PB81-157919

Second Survey of Dry SO2 Control Systems

Radian Corp
Durham, NC

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

Feb 81

U.S. Department of Commerce
National Technical Information Service
NTIS.

PB81-157919

United States
Environmental Protection
Agency

EPA-600/7-81-018
February 1981

EPA

Research and Development

SECOND SURVEY OF DRY SO_2 CONTROL SYSTEMS

Prepared for

OFFICE OF AIR QUALITY PLANNING AND STANDARDS
REGIONAL OFFICES 1 - 10

Prepared by

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/7-81-018		PB81 157919

4. TITLE AND SUBTITLE	5. REPORT DATE
Second Survey of Dry SO_2 Control Systems	February 1981
	6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
M. E. Kelly and S. A. Shareef	DCN 80-203-001-15-12

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Radian Corporation 3024 Pickett Road Durham, North Carolina 27705	1NE827
	11. CONTRACT/GRANT NO.
	68-02-3171, Task 15

12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711	Final; 3/80-9/80
	14. SPONSORING AGENCY CODE
	EPA/600/13

15. SUPPLEMENTARY NOTES: IERL-RTP project officer is Theodore G. Brna, Mail Drop 61, 919/541-2683. This supplements report EPA-600/7-80-030.

16. ABSTRACT: The report is an updated assessment of dry flue gas desulfurization (FGD) systems that reviews current and recently completed research, development, and commercial activities in the U.S. since October 1979, including: (1) spray dryers with a fabric filter or an electrostatic precipitator (ESP), (2) dry injection of alkaline material into flue gas combined with particulate collection in an ESP or fabric filter, and (3) combustion of coal/alkali fuel mixtures. Spray drying remains the only commercially applied dry FGD process. Since the last survey, completed late in 1979, eight utility and two industrial spray drying systems have been sold. Nine of them use lime as the sorbent, and nine use a fabric filter for particulate collection. Removal guarantees for SO2 range from 62 to 85%, depending on coal sulfur content. Two full-scale industrial spray drying systems are currently operating. The first large utility system is scheduled for startup early in 1981. Several publicly and privately funded pilot-scale programs have been completed in the past year. EPA is currently funding three such programs (two spray drying and one dry injection), as well as development of two combustion modification processes for SO2 control (combustion of coal/limestone pellets and of a pulverized coal/alkali mixture in a low-NOx burner). The DoE and others are studying dry injection on a pilot scale.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Filtration	Pollution Control	13B
Flue Gases	Electrostatic Precipitation	Stationary Sources	21B
Desulfurization		Dry Processes	07A,07D
Sulfur Oxides	Alkalies	Fabric Filters	07B
Assessments			14B
Spray Drying			13H
Fabrics			11E

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	88
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

EPA-600/7-81-018
February 1981

SECOND SURVEY OF

DRY SO_2 CONTROL SYSTEMS

by

Mary E. Kelly and S.A. Shareef

Radian Corporation
3024 Pickett Road
Durham, North Carolina 27705

EPA Contract No. 68-02-3171, Task 15

Project Officer

Theodore G. Brna

Utilities and Industrial Power Division
Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711

Prepared for

OFFICE OF ENVIRONMENTAL ENGINEERING AND TECHNOLOGY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, DC 20460

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory (RTP), U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

This report is an update of the first survey report on the status of dry flue gas desulfurization (FGD) processes in the United States published in February 1980. This updated assessment of the dry FGD systems is based on review of current and recently completed research, development, and commercial activities. Dry FGD systems covered include: (1) spray dryers with a fabric filter or an electrostatic precipitator (ESP), (2) dry injection of alkaline material into flue gas combined with particulate collection in an ESP or a fabric filter, and (3) combustion of coal/alkali fuel mixtures.

Spray drying continues to be the only commercially applied FGD process. Since the last survey was completed in the Fall of 1979, eight new utility and two new industrial spray drying systems have been sold. Almost all of these new systems use a lime sorbent and include a fabric filter for particulate collection. Removal guarantees for SO_2 range between 62 and 85 percent, depending on coal sulfur content. Two full-scale industrial spray drying systems are currently in operation, with the first large utility system scheduled for start-up in the Spring of 1981.

A number of pilot-scale demonstration programs funded by vendors and/or utilities have been completed in the past year. The Environmental Protection Agency is currently funding three demonstration programs (two spray drying and one dry injection). The Agency is also funding development of two combustion processes for SO_2 control: (1) combustion of coal/limestone fuel pellets and (2) combustion of a pulverized coal/alkali fuel mixture in a low-NO_x burner. The Department of Energy and a few vendors, as well as EPA, are continuing to investigate dry injection through pilot scale demonstration programs. Favored sorbents for dry injection include nahcolite, trona, and upgraded trona (90 percent $NaHCO_3$).

CONTENTS

Abstract ii
Tables v
Figures vi
Acknowledgements vii

1.0 Introduction 1

1.1 Report Organization 1
1.2 Technical Glossary 2
1.3 Types of Dry FGD Systems 3
1.3.1 Spray Dryer Systems 4
1.3.2 Dry Injection System 8
1.3.3 Combustion of Coal/Limestone Fuel Mixture . . 10
1.4 References 11

2.0 Overview 12

2.1 Summary of New Developments 12
2.2 Spray Dryer Systems 13
2.2.1 Commercial Activities 13
2.2.2 Research and Development 19
2.3 Dry Injection Systems 21
2.4 Combustion of Coal/Alkali Fuel Mixtures 22
2.5 State-of-the-Art Assessment 22
2.5.1 Advantages/Disadvantages of Dry FGD vs. Conventional Wet Scrubbing 24
2.5.1.1 Spray Drying 24
2.5.1.2 Dry Injection 27
2.5.1.3 Combustion of Coal/Alkali Fuel Mixtures 27
2.5.2 Areas for Further Research 27
2.6 References 28

3.0 Current and Recently Completed Activities 29

3.1 Babcock and Wilcox 29
3.2 Buell/Anhydro and EPA/Buell 36
3.3 Combustion Engineering 38
3.4 DOE/Grand Forks Energy Technology Center 42
3.5 DOE/Pittsburgh Energy Technology Center 43
3.6 Ecolaire 44
3.7 Electric Power Research Institute 46
3.8 Energy and Pollution Control, Inc. 49
3.9 EPA/Battelle - Columbus Labs 50
3.10 EPA/Energy and Environmental Research Corp. (EERC) . . . 57
3.11 Flakt, Inc. 58

CONTENTS (Cont.)

3.12	Joy/Niro	60	60
3.13	Kennecott Corporation (Carborundum Environmental Systems	65	65
3.14	Koch Engineering	66	66
3.15	Mikropul	67	67
3.16	Research-Cottrell (Cottrell Environmental Sciences) and EPA/Cottrell Environmental Sciences	68	68
3.17	Rockwell International	71	71
3.18	Stork-Bowen Engineering, Inc.	74	74
4.0	Recent Dry FGD Literature	78	78
Appendix		80	80

TABLES

Number		Page
2-1	Key Features of Commercial Spray Drying Systems Sold to Date	14
2-2	Firms Offering a Commercial Spray Drying FGD System	18
2-3	Major Spray Drying Demonstration Activities	20
2-4	Current Dry Injection Programs	23
2-5	Base Case Comparison of Capital Investments and Annual Revenue Requirements for Spray Dryer Design and Limestone Slurry Process	26
3-1	Jim Bridger Station System Specifications	32
3-2	Craig Station Dry FGD System Specifications	35
3-3	Pilot Plant Test Results from Sherburne County Generating Station	41
3-4	Results with Nahcolite - EPRI/KVB Lab Tests	47
3-5	Results with Trona - EPRI/KVB Lab Tests	47
3-6	Comparison of Physical Properties of Raw Coal and Fuel Pellets	52
3-7	Model Spreader Stoker Experiments	53
3-8	Checkout Tests for Coal/Limestone Pellets	54
3-9	Emission Data Summary for Fuel Pellet Demonstration	54
3-10	Sulfur Balance for Combustion of Coal/Limestone Pellets	54
3-11	Summary of Limestone/Coal Pelletizing Process Costs	56
3-12	Stork-Bowen/Leisegang Installation at Klockner-Werke AG, Mannestaedt Plant, West Germany (FRG)	77

FIGURES

Number		Page
1-1	SO_2 removal for various absorber outlet temperatures . . .	6
1-2	Typical spray dryer/particulate collection flow diagram .	7
1-3	Nahcolite dry injection flow diagram	9
3-1	Jim Bridger Station flow diagram	31
3-2	Laramie River Station flow diagram	34
3-3	Schematic flow diagram of C-E's Pilot Plant at Sherburne County Generating Station	40
3-4	Stork-Bowen/Leisegang Process for gas cleaning	75

ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation to the numerous vendors and agencies who took the time to provide information for this survey. Their help, given always in a cooperative spirit, has made possible a complete and informative survey. Thanks go also to Dr. T.G. Brna, the EPA Project Officer for his thorough and constructive review.

SECTION 1

INTRODUCTION

This report is a semi-annual update on the status of dry flue gas desulfurization (FGD) processes in the United States for both utility and industrial applications. Throughout this report, dry FGD will be defined as any process which involves contacting a sulfur-containing flue gas with an alkaline material and which results in a dry waste product for disposal. This includes (1) systems which use spray dryers for a contactor with subsequent baghouse or electrostatic precipitator (ESP) collection of waste products; (2) systems which involve dry injection of alkaline material into the flue gas with subsequent baghouse or ESP collection; and (3) other varied dry systems which are primarily concepts that involve addition of alkaline material to a fuel prior to combustion. This definition of dry systems excludes several dry adsorption or "acceptance" processes, such as the Shell/UOP copper oxide process and the Bergbau-Forschung adsorptive char process since the status of these processes has been documented in previous EPA reports. Fluidized bed combustion has also been excluded.

Also excluded was the regenerable Rockwell Aqueous Carbonate Process (ACP) which, although based on SO_2 removal with a spray dryer, does not fit the limitation of this study as being a "throwaway" system. However, the open loop, spray dryer contactor portion of the Rockwell process had been adapted for a "throwaway" system and, as such, has been included here.

1.1 REPORT ORGANIZATION

Section 2 presents an overview of the major types of dry FGD processes considered in this survey and includes:

1) A discussion of the commercial and developmental activities for each type of process (spray drying, dry injection, and combustion of a coal/limestone fuel mixture).

2) An assessment of the state-of-the art for each type of process.

3) A brief comparison of the advantages and disadvantages of dry and wet FGD systems.

4) A discussion of areas for further research.

Section 3 presents a summary of current and recently completed dry FGD research and development activities and commercial projects. In this section, each organization involved with dry FGD processes is discussed with respect to type(s) of systems being developed and marketed, current and future research and development programs, and commercial sales summaries. This report also contains a reference section and an appendix listing metric conversions since virtually all work has been reported in engineering units.*

1.2 TECHNICAL GLOSSARY

Definitions for several terms that are used frequently throughout this report to describe the operation of dry FGD systems are as follows:

Stoichiometry for dry scrubbing has been defined in most published literature as the moles of fresh sorbent introduced to the system divided by the moles theoretically required for complete reaction with all of the SO_2 entering the system whether or not all the SO_2 is removed. It should be noted that this definition results in a lower figure for the stoichiometric ratio (SR) as compared to the conventional definition for wet scrubbing which is based on moles of SO_2 removed by the system. For example, a reported stoichiometric ratio of 1.2 for a dry system achieving 80 percent SO_2 removal would be equivalent to a SR of 1.5 for a wet scrubbing system.

Sorbent utilization is defined as the percent SO_2 removal achieved by the system divided by the stoichiometry:

$$\frac{\left[\dfrac{\text{moles } SO_2 \text{ removed}}{\text{moles } SO_2 \text{ entering system}} \times 100\right]}{\left[\dfrac{\text{moles sorbent entering system}}{\text{moles sorbent required to react with } SO_2 \text{ entering}}\right]} = \text{(percent) utilization}$$

If one defines the sorbent for a calcium-based system as CaO and the sorbent for a sodium-based system as Na_2O, one mole of sorbent reacts with one mole of SO_2. Consequently, the above expression reduces to:

$$\text{(percent) utilization} = \frac{\text{moles } SO_2 \text{ removed}}{\text{moles sorbent entering system}} \times 100$$

*It is EPA policy to report measurements in the International System (SI) of units. For clarity of presentation, units used in this report are those commonly used in engineering calculations in the U.S. Conversion factors are presented in the Appendix.

Since the moles of sorbent do not include alkalinity from other sources such as recycled fly ash, it is possible to see apparent utilizations of greater than 100 percent. That is, the alkalinity in recycled fly ash can react to remove SO_2, so that there are more moles of SO_2 removed than moles of fresh sorbent feed.

A spray dryer is defined as any apparatus in which flue gas is contacted with a slurry or solution such that the flue gas is adiabatically humidified and the slurry or solution is evaporated to apparent dryness. For FGD applications the material dried is often a calcium-based slurry or a sodium solution which reacts with flue gas sulfur during and following the drying process. The spray dryer can use rotary, two-fluid or nozzle atomization, and the vessel can be anything from the back-mix reactor typically used in spray dryer technology to a large horizontal duct.

Dry injection is defined as the process of introducing a dry sorbent into a flue gas stream. This can take the form of pneumatically injecting sorbent into a flue gas duct, precoating or continuously feeding sorbent onto a fabric filter surface, or any similar form of mechanically introducing a dry alkaline sorbent into a flue gas stream.

Coal/limestone combustion is defined as the process of burning a mixture of coal and limestone whereby the SO_2 released from the coal reacts with the limestone to form solid calcium salts that are collected with the ash. Two specific combustion processes are discussed: one involves burning a coal/limestone pellet in a stoker-fired boiler and the other involves burning a pulverized coal/limestone mixture in a low NO_x burner.

1.3 TYPES OF DRY FGD SYSTEMS

This section provides a general process description for each of the three technologies being considered (i.e.,spray drying, dry injection, and combustion of coal/alkali fuel mixtures).

1.3.1 Spray Dryer Systems

In these systems, flue gas at air preheater outlet temperatures (generally 250 to 400°F) is contacted with a solution or slurry of alkaline material in a vessel of 5 to 10 seconds residence time. Sodium carbonate and lime are the most widely used sorbents for spray drying. Sodium, being more water soluble, is more reactive. This increased solubility can, however, lead to waste disposal problems as discussed later in this report. The flue gas is adiabatically humidified to within 20 to 50°F of its saturation temperature by the water evaporated from the solution or slurry. As the slurry or solution is evaporated, liquid phase salts are precipitated and remaining solids are dried to generally less than one percent free moisture. These solids, along with fly ash, are entrained in the flue gas and carried out of the dryer to a particulate collection device. Reaction between the alkaline material and flue gas SO_2 proceeds both during and following the drying process. There is some debate about whether SO_2 removal occurs predominantly in the liquid phase, by adsorption into the finely atomized droplets being dried, or by reaction between gas phase SO_2 and the slightly moist spray-dried solids.

Using a spray dryer for a flue gas contactor involves adiabatically humidifying the flue gas to within some specified degrees above saturation. With set conditions for inlet flue gas temperature and humidity and for a specified approach to saturation temperature, the amount of water which can be evaporated into the flue gas is set by energy balance considerations. Liquid-to-gas ratios are generally in the range of 0.2 to 0.3 gal/kcf. The sorbent stoichiometry is varied by raising or lowering the concentration of a solution or weight percent solids of a slurry containing this set amount of water. While holding other parameters such as temperature constant, the obvious way to increase SO_2 removal is to increase sorbent stoichiometry. However, as sorbent stoichiometry is increased to raise the level of SO_2 removal, two limiting factors are approached:

1) Sorbent utilization decreases, raising sorbent and disposal costs.

2) An upper limit is reached on the solubility of the sorbent in the solution, or on the weight percent of sorbent solids in a slurry.

There are at least two methods of circumventing these limitations. One method is to initiate sorbent recycle, either using the solids dropped out in the spray dryer or the particulate collection device catch. This has the advantage of increasing the sorbent utilization, plus it can increase the opportunity for utilization of any alkalinity in the fly ash.

The second method of avoiding the above limitations on SO_2 removal is to operate the spray dryer at a lower outlet temperature; that is, a closer approach to saturation. Operating the spray dryer outlet at a closer approach to saturation has the effect of both increasing the residence time of the liquid droplets and increasing the residual moisture level in the dried solids. As the approach to saturation is narrowed, SO_2 removal rates and sorbent utilization generally increase dramatically. Figure 1-1 shows the relationship between SO_2 removal and outlet temperature for a low sulfur western coal. Since the mechanisms for SO_2 removal do not appear to be well understood, it is not obvious whether it is the increase in liquid phase (droplet) residence time, the increase in residual moisture in the solids, or both which accounts for the increased removal.

The approach to saturation at the spray dryer outlet is set by either the requirement for a margin of safety to avoid condensation in downstream equipment or restrictions on stack temperature. The spray dryer outlet can be operated at temperatures lower than these restrictions would otherwise allow if some warm or hot gas is bypassed around the spray dryer and used to reheat the dryer outlet gas. Warm gas (downstream of the boiler air heater) can be used at no energy penalty, but the amount of untreated gas involved in reheating begins to limit overall SO_2 removal efficiencies. Significantly less hot gas (upstream of the air heater) is required to heat, but an energy penalty, associated with the decrease in energy available for air preheat, comes with using this higher temperature gas. Figure 1-2, a general flow diagram of a spray dryer-based system, illustrates these two "reheat" options.

The spray dryer design can be affected by the choice of particulate collection device. Bag collectors have an inherent advantage in that unreacted alkalinity in the collected waste on the bag surface can react with remaining SO_2 in the flue gas. Some process developers have reported SO_2 removal on bag surfaces on the order of 10 percent of total removal. Because the fabric is somewhat sensitive to wetting, a margin above saturation temperature

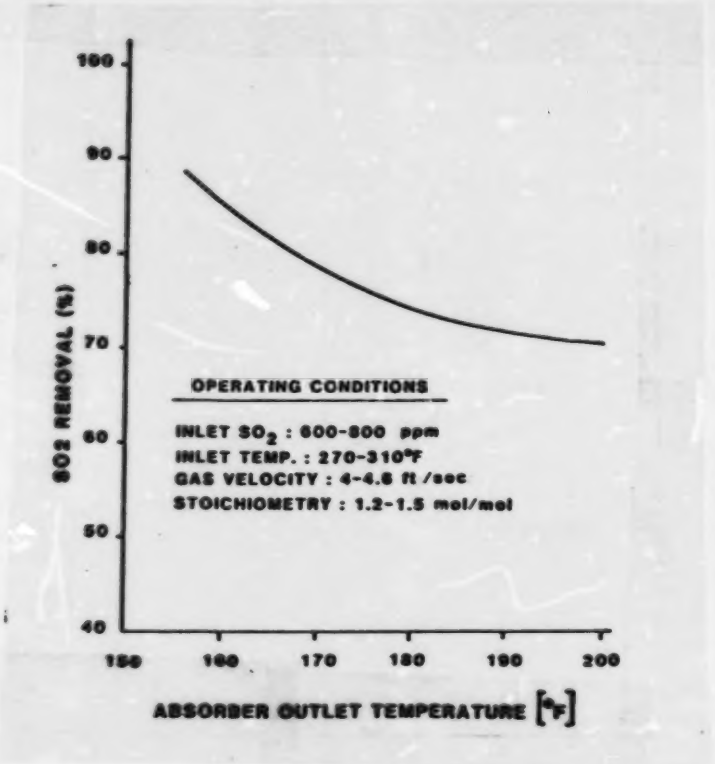

Figure 1-1. SO_2 removal for various absorber outlet temperature.

Source: Martin, J.R. et al. "C-E Dry Scrubber Systems: Application to Western Coals". (Presented at the American Power Conference, Chicago, Illinois, April 21-23, 1980.)

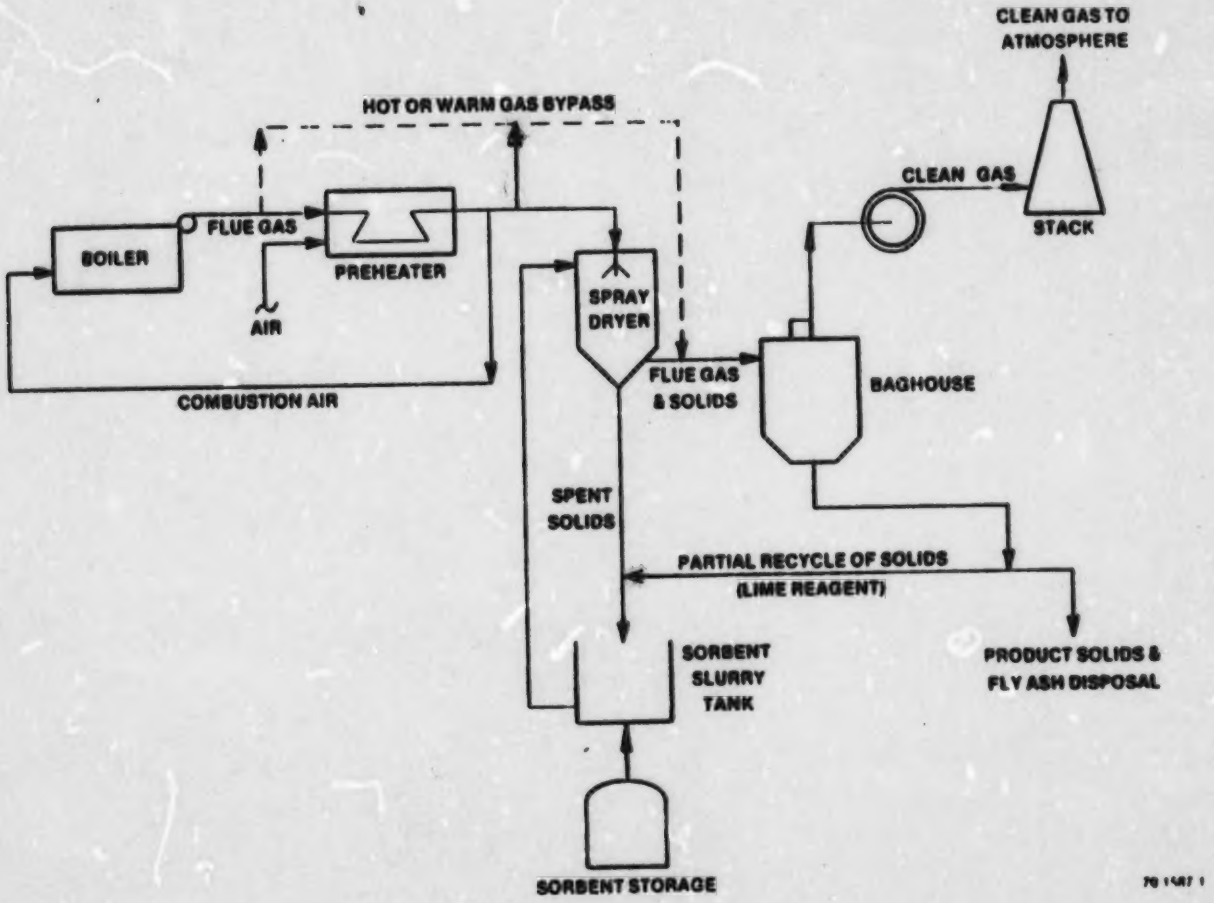

Figure 1-2. Typical spray dryer/particulate collection flow diagram.

must be maintained for bag protection. ESP collectors have not been demonstrated to achieve significant SO_2 removal. However, some vendors claim that the ESP is less sensitive to condensation and hence the spray dryer can be operated closer to saturation (about 20°F approach) resulting in increased SO_2 removal in the spray dryer.

The choice between sorbent types, (sodium- or calcium-based), use of recycle, use of warm or hot gas bypass, and types of particulate collection device tends to be rather site specific. Vendor and customer preferences, system performance requirements, and site-specific economic factors tend to dictate the system design for each individual application.

1.3.2 Dry Injection System

Dry injection schemes generally involve pneumatically introducing a dry, powdery alkaline material into a flue gas stream with subsequent particulate collection. A generalized flow diagram of this process is shown in Figure 1-3. The injection point has been varied from the boiler furnace area all the way to the flue gas entrance to an ESP or bag collector. Most dry injection schemes use a sodium-based sorbent. Lime has been tested but has not been demonstrated with much success. Many dry injection programs have used nahcolite as a sorbent. Nahcolite is a naturally occurring mineral, usually associated with western oil shale reserves, and is about 80 percent sodium bicarbonate. Sodium bicarbonate appears to be more reactive than sodium carbonate, because it loses both two moles of CO_2 and one of water in reaction, while sodium carbonate loses only one mole of CO_2 in reaction with SO_2. The following overall reactions illustrate this point:

$$2NaHCO_3 + SO_2 \longrightarrow Na_2SO_3 + H_2O + 2CO_2 \qquad (1\text{-}1)$$

$$Na_2CO_3 + SO_2 \longrightarrow Na_2SO_3 + CO_2 \qquad (1\text{-}2)$$

Since bicarbonate loses three moles for every mole of SO_2 removal, bicarbonate particles tend to have larger pore volumes and are apparently less susceptible to blinding on reaction than are sodium carbonate particles. Unfortunately, the availability of raw nahcolite in commercial quantities in the near future is questionable due to the substantial investment necessary before commercial scale mining can begin. However, the MultiMineral Corporation is currently obtaining data for an environmental impact study and they estimate that annual production of about 1 million tons of nahcolite would be achievable in about four years.[1] MultiMineral now operates a pilot nahcolite mine shaft near Denver, one of the few existing sources of nahcolite. Since the potentially favorable economics of dry injection are based to some extent on the use of inexpensive sorbents, the use of commercially refined sodium bicarbonate is prohibitively expensive. Recent research has been aimed at studying the use of raw and upgraded trona ore. The mineral trona contains one mole of sodium carbonate, one mole of sodium bicarbonate, and two waters of hydration ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$). Upgraded trona from the Owens Lake, California area, has the potential for providing a good compromise between reactivity, cost, and availability for use as a sorbent in the dry injection process.[2]

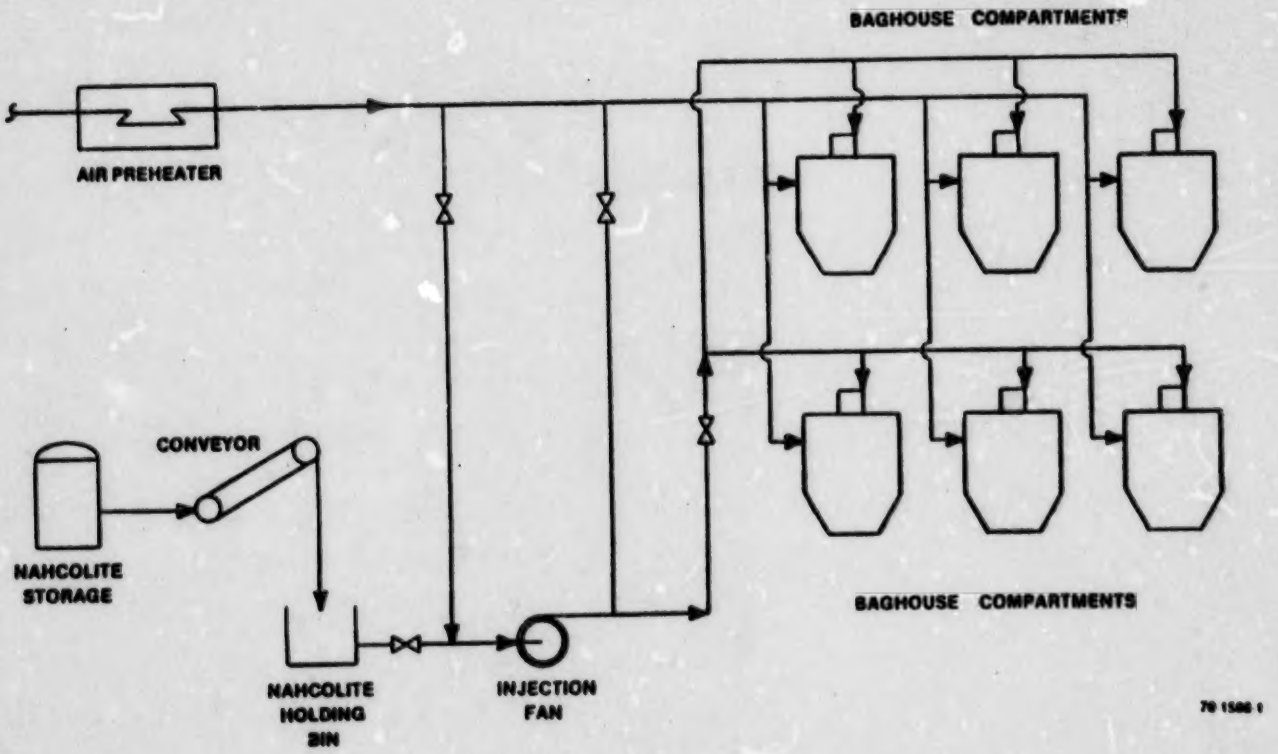

Figure 1-3. Nahcolite dry injection flow diagram.

Both baghouse and ESP collection devices have been tested with dry injection processes. However, the effect of the reaction between unspent sorbent on collecting bag surfaces and SO_2 remaining in the flue gas seems to overwhelmingly favor the bag collector. Since a significant portion of the SO_2 removal reaction appears to take place on the bag surface, various methods of feeding have been tested:

1) Continuous. After the bag is cleaned, sorbent entrained in the flue gas is continuously supplied to the bag surface from injection points located upstream of the baghouse.

2) Batch. After the bag is cleaned, all sorbent is added to the bag as a precoat before flue gas flow is resumed.

3) Semi-batch. This feeding method is a combination of methods 1 and 2. After bag cleaning some sorbent is precoated onto the bags and the remainder is added continuously at an upstream injection point.

Sorbent stoichiometry, sorbent particle size, location of injection point, temperature at the point of injection, baghouse air-to-cloth ratio, and bag cleaning frequency are also varied in dry injection programs.

1.3.3 Combustion of Coal/Limestone Fuel Mixtures

The current research on combustion of a coal/limestone fuel mixture has taken two forms:

1) Combustion of a coal/limestone pellet in an industrial spreader-stoker boiler.

2) Combustion of a pulverized coal/limestone mixture in a low-NO_x burner system.

Preliminary results of bench-scale test work on both processes have indicated that up to 80 percent of the available sulfur in the fuel can be retained by the limestone.[3] The ratio of calcium to sulfur in the coal/limestone fuel mixture is important in determining how much sulfur is retained, with higher Ca:S ratios resulting in greater SO_2 removal. The Ca:S ratio is limited, however, by effects on boiler operation and maintenance and fuel combustion properties.

A spreader-stoker boiler has been used in a demonstration program to test the combustion and sulfur retention characteristics of the coal/limestone pellet. The demonstration indicated that sulfur capture levels were achieved that would make the fuel pellet a viable SO_2 control option for low and medium sulfur coals.[4] Data suggest that improved SO_2 retention can be realized if the bed temperature is maintained below 2400°F.

The two-staged combustion concept was employed by Babcock & Wilcox (B&W) to design an advanced low-NO_x burner system. EPA has funded test work to develop the concept of firing a coal/limestone fuel mixture in a B&W low-NO_x burner to reduce SO_2 emissions. Tests conducted by the Energy and Environmental Research Corporation (EERC) with a Utah low sulfur coal have demonstrated 88 percent SO_2 removal with a 3:1 Ca:S mole ratio. This high SO_2 removal has been attributed to the lower flame temperature found in the low-NO_x burner which may help maintain limestone reactivity. EERC has reported that SO_2 removal increased substantially when the reagent was passed through the pulverizer with the coal. Further testing on a range of combustor sizes is planned during the next few months.

1.4 REFERENCES

1. Furlong, Dale A., T.G. Brna, and R.L. Ostop. "SO_2 Removal Using Dry Sodium Compounds." (Presented at the 89th National AIChE Meeting. Portland, Oregon. August 17-20, 1980.)

2. Ibid.

3. Giammar, Robert D. et al. "Limestone/Coal Pellet - A Viable Method to Control Emissions from Industrial Boilers." (Presented at the 73rd Annual Meeting of the Air Pollution Control Association, Montreal, Quebec. June 22-27, 1980.)

4. Ibid.

5. Blythe, G.M., J.C. Dickerman, and M.E. Kelly. "Survey of Dry SO_2 Control Systems." EPA-600/7-80-030. Radian Corporation. Durham, North Carolina. February 1980. (NTIS PB 80166853).

SECTION 2

OVERVIEW

Interest in dry flue gas desulfurization technology (dry FGD) has increased dramatically in the past few years, due to a combination of such factors as:

1) mandated increase in coal use,

2) more stringent environmental control regulations for utilities, requiring some type of post-combustion SO_2 control,

3) the attractiveness of handling a dry fly ash-like powder instead of a wet sludge, and

4) possible cost savings over conventional wet scrubbing systems, especially for low sulfur western coal applications.

The following sections provide a summary of the commercial and R&D status and a "state-of-the-art" description for each of the three technologies.

2.1 SUMMARY OF NEW DEVELOPMENTS

Spray drying continues to be the only commercially applied dry FGD process. Since the last survey was published in the Fall of 1979, eight new utility and two new industrial spray drying systems have been sold. All but one of these systems use a lime sorbent and all include a fabric filter for particulate collection. (One industrial system uses a sodium hydroxide solution in a spray dryer-based system designed to remove SO_2 and HCl from high temperature gases.) Removal guarantees for SO_2 range between 60 and 90 percent on the systems sold to date. The full-scale utility systems are designed for relatively low sulfur coals (0.5 to 1.3 percent sulfur), while higher sulfur coals (1.5 to 3 percent sulfur) are burned at two industrial systems that began operation in the past year and a half. All of the system designs are fairly similar, but there are variations between spray dryer design, atomization and slaking (lime preparation) techniques, and the use of gas bypass or solids recycle. The major spray dryer system vendors offer a basic system design with recycle or gas bypass being used depending on site-specific conditions.

A number of spray drying development programs, including two EPA-funded studies, have been recently completed or were in progress at the time of this report. (Each of these programs is described in more detail in Section 3.) Many of the development studies have been aimed at refining atomization and reagent preparation techniques in addition to obtaining a better understanding of process parameters such

as spray dryer gas-side temperature drop, approach to saturation at the dryer outlet, solids recycle, effect of fly ash alkalinity, and the relationship between inlet SO_2 and sorbent stochiometric requirements. It appears that a prime benefit of these programs will be a clearer definition of the technical limits of spray drying as well as a better understanding of the process leading to optimization and possible application to high sulfur units.

Ongoing bench-scale studies being conducted by some vendors are aimed at obtaining a better understanding of the mechanisms of the reaction occurring in the spray dryer. A few, somewhat varied, theories have been advanced as a result of this work. Several waste disposal studies are also being conducted, with the prime objective being full characterization of the physical and chemical stabilities of the waste solids.

Dry injection development programs are being funded by EPA, DOE, and the Electric Power Research Institute (EPRI). Sodium-based sorbents are favored for dry injection; nahcolite, trona, and upgraded trona appear to be the most viable choices. Sorbent availability and waste disposal, as well as higher stochiometric requirements to achieve a given SO_2 removal continue to restrict the commercial application of dry injection at this time. Some developments have occurred, however, in securing potential commercial supplies of sorbent and improving SO_2 removal through sorbent pretreatment. Waste disposal studies aimed at characterization of solids properties and development of environmentally acceptable disposal practices are also being conducted.

Development of coal/limestone pellets and combustion of a coal/alkali fuel mixture in a low NO_x burner are continuing, under EPA-funding, on development- and pilot-scales, respectively. The relatively minimal equipment requirements of these techniques make them particularly attractive, but large-scale demonstrations and full characterization of the effects on boiler design and operation and particulate control remain to be completed.

2.2 SPRAY DRYER SYSTEMS

2.2.1 Commercial Activities

As mentioned above, spray drying is the only commercially developed dry FGD technology. To date, contracts have been awarded for ten utility and four industrial spray dryer-based systems. Table 2-1 lists the system purchaser and vendor along with key features of the commercial systems that have been sold.

TABLE 2-1. KEY FEATURES OF COMMERCIAL SPRAY DRYING SYSTEMS SOLD TO DATE

System Purchaser/Vendor Utility	Location/Size	System Description	Coal	SO_2 Removal Guarantee	Reported Capital Cost	Reported Operating Cost	Status
Otter Tail Power Co./ Rockwell Wheelabrator-Frye.	Coyote Station, Beulah, ND/ Unit 1, 410 MW(1,890,000 acfm).	Four parallel spray dryers, with 3 centrifugal atomizers each, followed by fabric filter with dacron bags. Will initially use commercial soda ash. Sorbent utilization guarantee of 80%.	North Dakota lignite; 0.78% S average; 7050 Btu/lb; 7% Ash.	70% for all fuels.	$32,000,000 ($78/kW)[a].	$6,580,000 ($2.5 mills/kWh)[a]. Does not include waste disposal.	Start-up scheduled for mid-1981.
Basin Electric Power Coop/ Joy-Niro.	Antelope Valley, Beulah, ND/ Unit 1, 430 MW (2,200,000 acfm).	Five parallel spray dryers (one spare), single rotary atomizer per dryer, followed by fabric filter with teflon-coated fiberglass bags. Lime sorbent with partial recycle of solids. Ball mill slaker.	North Dakota lignite; 0.68% S average; 1.22% S maximum.	62% for average S coal; 78% for maximum S coal.	$49,665,100 ($113/kW)[b].	$2,270,834/yr ($0.8 mills/kWh)[b]. Lime cost = $1,102,500 ($60/ton). Does not include waste disposal.	Start-up scheduled for April 1982.
Basin Electric Power Coop/ Babcock & Wilcox.	Laramie River, Wheatland, Wyoming/Unit 3, 500 MW (2,810,000 acfm).	Four parallel reactors (one spare) with 12 fluid nozzles each. Each reactor followed by an ESP. Lime sorbent, no solids recycle.	Wyoming subbituminous, 0.54% S average; 0.81% S maximum; 8140 Btu/lb; 8% Ash.	82% for average S coal; 90% for maximum S coal.	$49,807,000 ($83/kW)[b].	$2,571,000/yr ($0.7 mills/kWh)[b]. Lime cost = $1,396,570 ($60/ton). Does not include waste disposal costs.	Start-up scheduled for Spring 1982.
Northern States Power/ Joy-Niro.	Riverside Station / Units 6 and 7, 110 MW (680,000 acfm); Retrofit.	One spray dryer with rotary atomizer. Will initially be demonstrated at 300,000 acfm with ESP. Full flow with fabric filter. Ball mill and attrition slaker for lime sorbent.	1% S Montana coal; 3.0 to 3.5% S Illinois coal	Varying between 70 and 90% during demonstration tests.	$18,000,000[b]	Not available.	Testing with existing ESP scheduled to start Fall 1980. Fabric filter on-line in early 1981.
Tucson Electric/ Joy-Niro. (2)	Springerville Station/ Units 1 and 2; 350 MW each.	Spray dryer/fabric filter design. Lime sorbent. Rotary atomization.	New Mexico coal; 0.69% S.	61%.	Not available.	Not available.	Unit 1 scheduled to start-up in late 1984; Unit 2 in 1986.
United Power Association/ Research-Cottrell.	Stanton Station, Stanton, North Dakota/65 MW.	Spray dryer/fabric filter rotary atomizers, possibly multiple atomizers per dryer. Lime sorbent.	Low and intermediate sulfur subbituminous Montana coal.	Not available.	Not available.[b]	Not available.	Start-up scheduled for 1981.

TABLE 2-1. (Continued). KEY FEATURES OF COMMERCIAL SPRAY DRYING SYSTEMS SOLD TO DATE

System Purchaser/Vendor Utility	Location/Size	System Description	Coal	SO_2 Removal Guarantee	Reported Capital Cost	Reported Operating Cost	Status
Platte River Power Authority/ Joy-Niro.	Rawhide Station/Unit 1 250 MW.	Spray dryer/fabric filter design. Rotary atomizers. Lime sorbent.	Western subbituminous coal; 1.3% S.	80%.	Not available.	Not available.	Start-up scheduled for 1983.
Colorado-Ute Association/ Babcock & Wilcox.	Craig Station/Unit 3 450 MW.	Horizontal spray dryers with nozzle atomizers, followed by fabric filter. Solids recycle. Ball mill slaker for lime sorbent.	0.70% S, 8950 Btu/lb, 14% Ash design coal; 0.40% S, 10250 Btu/lb, 8% Ash performance coal.	87% for design coal.	($100/kW)	Not available.	Initial operation in November 1982. Commercial operation in April 1983.
Sunflower Electric Coop/ Joy-Niro.	Holcombe Station/Unit 1 310 MW.	Spray dryer/fabric filter. Rotary atomization. Lime sorbent.	Western subbituminous coal.	80%.	Not available.	Not available.	Start-up scheduled for 1983.
Industrial							
Celanese Fibers Co./ Rockwell/Wheelabrator-Frye.	Amcelle plant, Cumberland, Maryland/65,000 acfm (110,000 lb steam/hr).	Spray dryer with single rotary atomizer followed by fabric filter with felt/ fiberglass bags. Paste slaker for lime sorbent. No solids recycle.	1.5% S and 2 to 2.5% S eastern coals.	70% for 1.5% S coal, 81% for 2.0% S coal.	$1,250,000[d].	Not available.	Operational. Passed Maryland state compliance tests in February 1980. Has achieved guaranteed removal.
Strathmore Paper Co./ Nirotpul, Inc.	Woronco, Massachusetts/ 40,000 acfm (85,000 lb steam/hr).	Spray dryer with four two-fluid nozzles, followed by fabric filter with specially finished acrylic bags.	2.3 to 3% S eastern coal.	75%.	$1,400,000[d,e].	$600/day[e].	Operational. Now achieving removal guarantee.
University of Minnesota/ Rosemount Development Co. (Environmental Products Division).	Univ of Minnesota/2 Units at 120,000 acfm each.	Spray dryer with single rotary atomizer followed by fabric filter with fiberglass bags. Lime sorbent.	Subbituminous coal; 0.6 to 0.7% S.	70%.	$3,300,000[d,f].	Not available.	Commercial operation in Fall 1981.
Calgon/Niro-Joy	57,000 acfm.	Spray dryer/fabric filter. Rotary atomizer. Soda ash sorbent. Removing SO_2 and HCl from 1700°F gases. Solids recycle.	1 to 2% S coal, [illegible] ppm SO_2, 8000 ppm halides.	75% SO_2; 90 % HCl	$1,600,000[d,g].	Not available.	Under construction.

FOOTNOTES TO TABLE 2-1:

[a]Capital Cost for complete turnkey installation from air preheater outlet to stock connection, exculding I.D. fans (1977$). Source: Johnson, O.B. et. al. "Coyote Station, First Commercial Dry FGD System." (Presented at 41st Annual American Power Conference, Chicago, Illinois. April 23-25, 1979.)

[b]Evaluation based on 35-year plant life, 75% capacity factor (1981$). Source: Janssen, K.E. and R.L. Eriksen. "Basin Electric's Involvement with Dry Flue Gas Desulfurization." In Proceedings; Symposuim on Flue Gas Desulfurization - Las Vegas, Nevada, March 1979; Volume 2. EPA-600/7-79-167. July 1979. pp 629-653.

[c]Kelly, M.E. and S.A. Shareef. Meeting notes at Babcock & Wilcox. Barberton, Ohio. June 1980.

[d]Stern, J.L. "Dry Scrubbing for Industrial Flue Gas Desulfurization: State-of-the Art, 1980." (Presented at the 89th National Meeting of AICHE. Portland, Oregon. August 17-20, 1980.)

[e]From "ground-up". (1979$)

[f]"Straight-through system". (1980$)

[g](1980$)

Only two systems, both industrial, were operational at this writing. The Rockwell/Wheelabrator-Frye system at Celanese Fibers Company's Amcelle plant passed Maryland state SO_2 compliance tests (70 lb SO_2/hr emission limit) in February 1980. Celanese is now operating the system, with intermittent technical support from Rockwell/Wheelabrator-Frye. The system at Strathmore paper has been operated by the vendor (Mikropul) since July of 1979. Although there were some initial problems with atomization, Mikropul has reported an availability during the past eleven months of about 90 percent based on boiler demand.

Both of the operational industrial systems burn medium sulfur eastern coals (1.5 to 3 percent sulfur) and are designed for 70 to 87 percent SO_2 removal with lime sorbents. Both designs include a spray dryer followed by a fabric filter. The Mikropul system uses four two-fluid nozzles for atomization and a pulse-jet fabric filter. A single rotary atomizer and a pulse-jet fabric filter are included in the Rockwell/Wheelabrator-Frye system at Celanese.

The first large scale utility commercial system start-up is scheduled for the Rockwell/Wheelabrator-Frye system at Otter Tail Power Company's Coyote Station. The 110-MW Joy/Niro retrofit system at Northern States Power's Riverside Station is scheduled to begin operation in the Fall of 1980, but will initially be operated as a demonstration unit. Testing at about half the maximum gas flow rate is scheduled to begin this fall. An existing ESP will be used until the baghouse portion of the system is completed (early 1981).

As shown in Table 2-1, all the utility systems (with the exception of Northern States Power) are designed for relatively low sulfur western coals. Removal guarantees range from 61 to 87 percent. Almost all of the utility systems use a lime sorbent and include a fabric filter for collection of fly ash and the dried product solids. Exceptions include the Coyote system which will use a sodium-based sorbent (initially commercial soda ash) and the B&W system at Laramie River that will use four ESPs rather than a fabric filter. Depending on site specific factors, some designs include hot or warm gas bypass and/or recycle of spent solids mixture.

In addition to the commercial systems already sold, there has been an increasing number of utilities (and industrial users) that have specified dry FGD for SO_2 control system bids. It is estimated that five to seven bids for utility systems were under evaluation at this writing. This expanding market is reflected in the number of firms currently offering a commercial spray dryer-based dry SO_2 removal system. Table 2-2 lists the firms offering a spray drying system and highlights some of their respective design features.

The differences between system designs include the type of atomizer (nozzle or rotary) and the atomizer configuration in the spray dryer.

TABLE 2-2. FIRMS OFFERING A COMMERICAL SPRAY DRYING FGD SYSTEM

Firm	Design features[a]	Number of Systems Sold
Babcock and Wilcox	Horizontal dryers with "Y-jet" steam/air atomized nozzles. Favor ESP but also offer fabric filter.	2 utility (does not plan to bid industrial)
Buell/Anhydro	Spray dryer followed by fabric filter. Single centrifugal atomizer per dryer.	None
Combustion-Engineering	Spray dryer followed by fabric filter. Multiple ultrasonic nozzles per dryer.	None
Ecolaire	Spray dryer followed by fabric filter. Tested primarily with single rotary atomizers.	None
Flakt	Horizontal and vertical spray dryer with either fabric filter or ESP. Nozzle atomization.	None
Joy/Niro	Spray dryer followed by fabric filter. Single rotary atomizer per dryer.	6 utility,[b] 1 industrial
Kennecott	Spray dryer/fabric filter with single rotary atomizers	1 industrial (2 units)
Koch	Spray dryer. Nozzles "seem likely choice."	None
Mikropul	Spray dryer/fabric filter. Multiple nozzle atomizers per dryer. Also offer centrifugal atomizers.	1 industrial
Research-Cottrell	Spray dryer/fabric filter. Multiple rotary atomizers per dryer. Nozzle atomizers for sodium-based systems.	1
Rockwell	Spray dryer/fabric filter. Rotary atomizers - multiple per dryer for utility, single for industrial.	1 industrial, 1 utility
Stork-Bowen Engineering	Spray dryer followed by a cyclone and a Leisegang scrubber or followed by a baghouse.	No systems in U.S.

[a]The reported design features are based on commercial systems sold to date and information presented in Section 3. Many vendors may offer additional designs depending on the system purchaser's specifications.

[b]Includes Riverside unit at Northern States Power which will be operated as demonstration system for the near future.

Several vendors have selected rotary or centrifugal atomizers over nozzles, claiming there are more pluggage or erosion problems associated with nozzles, especially for lime slurries. Nozzles, however, generally have lower capital and operating costs. Some vendors offer a "multiple atomizers per dryer" design. This has the advantage of allowing the absorber to remain operational even when a particular atomizer has to be taken out of service. The use of multiple atomizers in non-FGD applications, however, is not very common.

Other basic system design differences include:

1) use of an ESP instead of a fabric filter for particulate collection (most use fabric filters),

2) variations in size and shape of spray dryer (top, side or bottom gas entry; single- or two-point discharge; horizontal dryer or cylindrical tower with conical bottom, cocurrent or countercurrent flow), and

3) reagent preparation technique for lime (less costly paste slakers with grit removal or ball mill slakers that produce more finely ground product).

2.2.2 Research and Development

In addition to developing a capacity for supplying a commercial spray drying system, many firms, as well as EPA, are involved in pilot-scale demonstration programs and fundamental research on the finer points of the technology.

Table 2-3 shows current and recently completed major demonstration activities. These systems range in size from 8500 to 120,000 acfm. Two of these programs, at Colorado Springs' Martin Drake Station and Public Service of Colorado's Comanche Station, are being supported by EPA. The other programs are being funded by the vendor and/or the respective utility. Detailed results of the privately funded demonstration tests are not generally available. However, some general descriptions of current activities can be provided. Many of the studies are investigating various portions of the spray dryer-based process including:

1) fabric filter vs. ESP collection with regard to collection efficiency and effect on SO_2 removal,

2) atomization technique,

3) reagent preparation techniques,

4) reactivity of various sodium- and calcium-based sorbents, and

5) waste solids disposal.

TABLE 2-3. MAJOR SPRAY DRYING DEMONSTRATION ACTIVITIES[a]

Vendor	Location	Size	Comments
Babcock & Wilcox	Pacific Power & Light's Jim Bridger Station	120,000 acfm	Testing in progress.
Buell Envirotech/ Anhydro	Colorado Springs-Martin Drake Station	8,500 acfm	Also EPA-funded dry injection program at same location.
Combustion Engineering	Northern States Power Sherburne County Unit #1	20,000 acfm	Testing complete.
Combustion Engineering	Alabama Power-Gadsden Station (under construction)	100,000 acfm	Testing to start in September 1980 soon after construction is completed.
Ecolaire Systems, Inc.	Nebraska Power - Gerald Gentlemen Station	10,000 cfm mobile pilot plant	Testing in progress.
Research-Cottrell (Cottrell Environmental Sciences)	Public Service of Colorado's Comanche Station	10,000 acfm	EPA-funded, test in progress.

[a] More information on each of these programs can be found in Section 3.

Key process parameters that are varied to characterize and optimize the process include SO_2 inlet concentration, sorbent stochiometry, flue gas temperature drop over the spray dryer, gas residence time in dryer, approach to saturation, atomizer disc speed (rotary atomizers), sorbent slurry or solution concentration, and source (spray dryer fallout or collected solids) and amount of solids recycle. In addition to characterizing the process, an objective of many of the programs is to demonstrate the system's capability to achieve the desired SO_2 removal on a sustained basis.

Many vendors, along with EPA and DOE, are also conducting smaller scale fundamental research. Objectives of this work include obtaining a better understanding of the reaction mechanisms and definition of the most important variables affecting the rate and degree of completion, characterizing the effects of atomized droplet size, sorbent particle size, and fly ash alkalinity, and characterizing the chemical and physical stability properties of sodium- and calcium-based waste solids.

Many of the research and development activities are geared toward increasing the applicability of spray drying to high sulfur coal-fired units. Possible technical and economic limitations of spray drying are discussed briefly in Section 2.5.

2.3 DRY INJECTION SYSTEMS

Dry injection is potentially a very attractive alternative for combined removal of SO_2 and fly ash with minimized equipment requirements, relative to wet scrubbing or spray drying, but the commercial development of this technology has been constrained by several factors. Major restraints to the development of commercial dry injection systems have been uncertainty regarding (1) the availability of the preferred sorbent (nahcolite) and (2) acceptable disposal practices for the sodium-based waste solids.

Past and current studies[1,7] have shown that dry injection of nahcolite (a form of naturally occurring sodium bicarbonate usually found with oil shale deposits) into the dirty flue gas stream and collection of the solids in a fabric filter results in 60 to 80 percent SO_2 removal at moderate gas temperatures (300 to 350°F) and inlet SO_2 concentrations (<2000 ppm). Nahcolite utilization is generally less than 80 percent. Trona has been found to be less reactive than nahcolite and thus higher stochiometries are required to achieve the same SO_2 removal. Lime and limestone have been demonstrated to achieve significant SO_2 removal only at much higher gas temperatures[7] (>600°F). Nahcolite, however, has not been available in the quantities required for large scale commercial operations since substantial capital investments are required before commercial mining of nahcolite can begin, and there is no other established market for nahcolite. The nahcolite for current dry injection tests is obtained from a small pilot shaft in Colorado. Upgraded trona (90 percent $NaHCO_3$) from Owens Lake, California, is available from Lake Minerals Corporation.[2]

An economically attractive method for disposal of the sodium-waste solids in an environmentally acceptable manner has yet to be defined. Sodium waste materials are highly leachable and may result in contamination of ground water.

Despite these constraints, several dry injection development studies are being conducted (Table 2-4). The major driving force, as mentioned earlier, is the potential capital and operating cost savings over conventional wet SO_2 removal. Three of the four programs are being funded by government agencies, EPA and DOE, while the fourth and largest is being funded by the Electric Power Research Institute (EPRI). Objectives of the program include improvement of sorbent reactivity (utilization), particularly for the more available sorbents such as trona, and characterization of the physical and chemical properties of the waste solids leading to development of acceptable disposal techniques. The process parameters varied during the tests include sorbent feeding method (continuous, batch, precoat, or combination of those methods), cleaning cycle time, injection temperature, sorbent particle size, SO_2 inlet concentration, and sorbent stoichiometry. Sorbents being investigated are nahcolite, trona, upgraded trona, commercial sodium bicarbonate, and sodium carbonate.

2.4 COMBUSTION OF COAL/ALKALI FUEL MIXTURES

The two most promising variations of this process are both being developed under EPA funding. Test work on the combustion of coal/limestone pellets in spreader stokers is being conducted by Battelle Laboratories. A 14-day test of a 3.5:1 Ca:S (mole ratio) pellet was scheduled to begin in November 1980 on a 60,000 lb steam/hr boiler at General Motors' Indianapolis plant. Laboratory scale tests have shown 50 to 75 percent retention of the available fuel sulfur with the 3.5:1 Ca:S pellet.

Energy and Environmental Research, Inc. (EERC) is continuing work on combustion of a pulverized coal/alkali fuel mixture in a low-NO_x burner on a 70,000 Btu/hr scale. Limestone and trona have both been tested, with limestone showing higher sulfur retention (50 to 70 percent retention at a stochiometric ratio of 2 to 3). The technique has also been demonstrated to achieve significant NO_x removal. Future test work will be carried out on the 1, 10, and 50 x 10^6 Btu/hr scales.

Research and development activities with both processes are focused on (1) characterizing effects on boiler design, operation, and maintenance; (2) demonstrating the degree of SO_2 removal achievable; and (3) determining the effects of the resulting increased particulate loading.

2.5 STATE-OF-THE-ART ASSESSMENT

The interest in dry FGD technology is considerable, as evidenced by the increased commercial and research and development activities over the past year. Dry FGD has several potential advantages over conventional

TABLE 2-4. CURRENT DRY INJECTION PROGRAMS

Vendor	Location	Size	Comments
EPA/Buell-Envirotech	Colorado Springs - Martin Drake Station	4500 acfm	Testing completed in May 1980. EPA funded.
DOE/Grand Forks Energy Technology Center	GFETC Labs	200 acfm	Testing complete. Report expected in Fall 1980.
DOE/Pittsburgh Energy Technology Center	PETC Labs	500 lb coal/hr furnace	Testing in progress.
EPRI/KVB	Public Service Company of Colorado - Cameo Station	20 MW_e	Testing in progress.

wet scrubbing, both technical and economic. At the present stage of development, there are, however, limits on the applicability of dry FGD processes. The following sections present these respective points. The final section discusses process areas requiring further investigation.

2.5.1 Advantages/Disadvantages of Dry FGD vs. Conventional Wet Scrubbing

In general, dry FGD is a potentially attractive alternative to conventional wet scrubbing because it results in a dry, easy-to-handle waste rather than a wet sludge. Also, for certain applications, there are potential capital and operating cost savings resulting from reduced equipment requirements, lower energy and water requirements, and relative process simplicity.

The advantages and disadvantages of each of the three technologies considered (spray drying, dry injection, and combustion of coal/alkali fuel mixtures) are discussed below. Since little short term data and no long term data are available on commercial dry FGD applications, the comparisons discussed here are based on pilot plant data, limited reported operating experience, and conceptual studies.

2.5.1.1 Spray Drying

Several papers and conceptual studies[3,4,5,6,7] have evaluated the potential technical and economic advantages of a spray dryer/baghouse system over a conventional wet lime/limestone process for low to medium sulfur coal applications. Technically, spray drying and wet FGD can be compared in four areas: reagent requirements, energy requirements, operation and maintenance requirements, and waste disposal requirements.

Dry systems require a significantly higher stochiometric ratio of sorbent on the basis of moles sorbent required per mole of SO_2 removed, the conventional definition of stochiometry for wet systems. Reported stochiometric ratios for dry systems, however, are based on moles of sorbent required per mole of SO_2 in the inlet flue gas. Thus, a reported stochiometric ratio (SR) of 1.2 for a dry system achieving 80 percent SO_2 removal would translate into a SR of 1.5 under the conventional definition for wet systems. It should also be noted that, in general, dry systems require a increased SR to achieve a given SO_2 removal at increased inlet SO_2 concentrations. This factor may pose a technical limit to application of spray drying to high sulfur coals, since the amount of liquid (and therefore sorbent) that can be sprayed into the gas is limited by the available flue gas temperature drop over the spray dryer. This temperature drop is in turn fixed by the inlet gas temperature, the margin of safety (in terms of degrees above the adiabatic saturation temperature) that must be maintained, and the overall SO_2 removal efficiency required (which limits warm or hot gas bypass). The maximum attainable solution concentration or weight percent solids in the sorbent slurry also limits the amount of sorbent that can be added per unit time.

The energy consumption of the dry system should be significantly less than for the wet scrubbing because of lower pumping requirements (lower L/G) and reduction or elimination of the need for flue gas reheat.

Several vendors claim that the spray dryer-based systems will have lower maintenance requirements and more operational flexibility than comparable wet systems.[2,5] Basin Electric Power Cooperative has cited process simplicity and potential high availability as major factors in their purchase of two dry systems.[5] Spray dryer system designs do not include sludge handling equipment or large slurry recirculation equipment, process areas that have been sources of high maintenance requirements in wet system commercial operating experience. The scaling potential in wet systems requires extra effort to maintain proper operation. This potential is limited in the spray dryer system because there is no wet/dry interface other than in the gas suspension, possibly making the process operation more flexible with respect to variations in boiler load and inlet SO_2 concentration.

Finally, the dry product solids resulting from spray drying may be easier to handle than wet sludge. Although the physical and chemical stabilities of the calcium-based salts have not been fully defined, they should have similar environmental impacts to wastes from lime/limestone wet systems. As discussed earlier, there are leachability and stability problems associated with wastes from sodium-based systems.

Economics appear to be one of the major driving forces behind selection of spray drying over conventional wet systems for low sulfur coal applications. Basin Electric evaluated the cost of a dry system to be 15 to 25 percent less over a 35-year plant life than a wet system for Laramie River and Antelope Valley, respectively.[2] In a recently completed conceptual study[4] the Tennessee Valley Authority (TVA) found the cost of a lime-based spray drying system to be considerably less than for a wet system (Table 2-5). The basis for this analysis was a new 500-MW plant burning a low sulfur western coal with a 70% SO_2 removal requirement. A similar conclusion (for low sulfur coals) was reached in another conceptual study conducted by American Air Filter.[8] However, the spray dryer-based system was at an economic disadvantage for coals with a sulfur content of about 1 percent or greater. An attempt to compare the bases for these different studies is out of the scope of this report. The higher reagent requirements and the reagent cost differential between lime and limestone may result in a significant economic disadvantage for spray drying for high sulfur applications.

TABLE 2-5. BASE-CASE COMPARISON OF CAPITAL INVESTMENTS AND ANNUAL REVENUE REQUIREMENTS FOR SPRAY DRYER AND LIMESTONE SLURRY PROCESS

	Generic lime spray dryer process	Limestone slurry process
Capital investment (1982 $)		
M$	66.2	93.2
$/kW	132.3	186.4
Total first-year revenue requirements (1984 $)		
M$	17.04	23.50
mills/kWh	6.20	8.55
Levelized annual revenue requirements (1984 $)		
M$	23.52	32.19
mills/kWh	8.55	11.71

Source: Reference 5, p xvii. Burnett, T.A. and W.E. O'Brien. "Preliminary Economic Analysis of a Lime Spray Dryer FGD System". EPA-600/7-80-050. Tennessee Valley Authority Office of Power. Muscle Shoals, Alabama. March 1980. (NTIS PB 80190051).

2.5.1.2 Dry Injection

The same advantages with respect to energy and operation and maintenance requirements that are discussed above should apply for a dry injection system. The equipment requirements for dry injection are significantly less than for conventional wet scrubbing or spray drying. However, the dry injection system has a distinct disadvantage with regard to reagent utilization and reagent related operating costs. Nahcolite utilization has been relatively low in tests conducted to date (60 to 80 percent), leading to fairly high reagent requirements to achieve high SO_2 removal. Also, sodium-based sorbents are much more reactive than lime or limestone but may be expensive. Considering these factors, it appears that the present dry injection technique would be limited to relatively low sulfur coals. Finally, there are environmental considerations associated with the disposal of sodium-based wastes.

2.5.1.3 Combustion of Coal/Alkali Fuel Mixtures

This technology has obvious economic potential because of relatively minimal equipment requirements and the fact that significant SO_2 removal has been demonstrated with limestone, a fairly low cost reagent. However, both processes (combustion of coal/limestone pellets and firing a pulverized coal/limestone mixture in a low-NO_x burner) are still in the early stages of development. Their effects on boiler design, operation, and maintenance have yet to be fully characterized. Also, these technologies are currently limited to specific boiler types, i. e. spreader stokers for the pellets and dry bottom pulverized coal boilers for the coal/limestone fuel mixture. Fuel sulfur content may be limited by the sheer volume of reagent required for higher sulfur applications and the resulting effects on boiler and particulate control device operation.

2.5.2 Areas for Further Research

Despite the rapid development of dry FGD technology, there are several areas requiring further research if the technology is to become a widely applicable alternative to conventional SO_2 control techniques.

Concerning spray drying, research effort in the following areas could serve to increase process applicability for units firing high sulfur coal:

1) improved understanding of the absorber and downstream SO_2/sorbent reaction mechanims,

2) improved reagent preparation techniques,

3) improved understanding of fly ash alkalinity utilization and investigation of various sorbent recycle schemes, and

4) development of a spray drying process using limestone or other less expensive but environmentally acceptable sorbents.

In addition to research in areas (1) through (3) above, dry injection work may also need to focus on improving the reactivity of sorbents more readily available than nahcolite.

Research into combustion of coal/alkali fuel mixtures will need to define the important process variables, such as bed temperature, and their effect on SO_2 retention, and further evaluate the long-term effects of firing fuel/alkali mixtures on boiler operations.

Waste disposal studies are important to all three technologies. The objectives of these studies would include characterization of physical and chemical stability and development of acceptable methods of disposal or reuse of the waste solids.

2.6 REFERENCES

1. Davis, W.T. et al. "Research on the Simultaneous Removal of SO_x and Particulates from Stoker-Fired Boilers." (Presented at the 70th Annual Meeting of the Air Pollution Control Association. Toronto, Canada. June 20-24, 1977.)

2. Furlong, Dale A., T.G. Brna, and R.L. Ostop. "SO_2 Removal Using Dry Sodium Compounds." (Presented at the 89th National AIChE Meeting. Portland, Oregon. August 17-20, 1980.)

3. Janssen, K.E. and R.L. Eriksen. "Basin Electric's Involvement with Dry Flue Gas Desulfurization." In: Proceedings; Symposium on Flue Gas Desulfurization - Las Vegas, Nevada, March 1979; Volume 2. EPA-600/7-79-167. July 1979. pp 629-653.

4. Hurst, T.B. "Dry Scrubbing Eliminates Wet Sludge". (Presented to the Joint Power Conference. Charlotte, North Carolina. October 7-11, 1979.)

5. Burnett, T.A. and W.E. O'Brien. "Preliminary Economic Analysis of a Lime Spray Dryer FGD System." EPA-600/7-80-050. TVA Office of Power. Muscle Shoals, Alabama. March 1980. (NTIS PB 801900051)

6. Kaplan, Steven M. and Karsten Felsvang. "Spray Dryer Absorption of SO_2 from Industrial Boiler Flue Gas." (Presented at the 86th National AIChE Meeting. Houston, Texas. April 1-5, 1979.)

7. Blythe, G.M., J.C. Dickerman, and M.E. Kelly. "Survey of Dry SO_2 Control Systems." EPA-600/7-80-030. Radian Corporation. Durham, North Carolina. February 1980. (NTIS PB 80166853)

8. Onnen, James. "Wet Versus Dry Sulfur Dioxide Removal Study." (Presented at the Third Annual Fabric Filter Alternatives Forum. Phoenix, Arizona. September 20-21, 1978.)

SECTION 3

CURRENT AND ON-GOING ACTIVITIES

This section summarizes pertinent activities of companies involved in current and on-going developments of dry FGD systems. Included here are background information on the companies, a summary of dry FGD-related research, a summary of commercial sales and marketing activities, and a description of the type(s) of dry FGD system the company is marketing or developing.

The discussions of current and on-going development activities are presented in alphabetical order by company name. The results of many of the current activities reported here are very preliminary and are unpublished. Consequently, much of the information was obtained through personal contact, either by telephone or meetings held with process vendors. For this reason, names of company representatives who may be contacted for additional information on their dry FGD activities are provided.

3.1 BABCOCK AND WILCOX

Address: Babcock and Wilcox
20 South Van Buren
Barberton, Ohio 44023

Babcock and Wilcox
Alliance Laboratory
P.O. Box 834
Alliance, Ohio 44601

Contacts for More Information:

Tom Hurst	Cecil Miller	J.B. Doyle
Barberton	Barberton	Alliance
(216) 753-4511	(216) 753-4511	(216) 821-9110

Background

Babcock and Wilcox (B&W) has a rather novel approach to spray drying technology. As opposed to the more standard back-mix type reactor and two-fluid nozzle or rotary atomization, B&W employs a horizontal reactor using "Y-Jet" nozzles which were adapted from their standard oil burner technology. Also, B&W favors ESP collection of the spent sorbent/fly ash mixture rather than baghouse collection which appears to be favored by other vendors.

In addition to the Laramie River Station's 500 MW unit, B&W has also been awarded a contract for a commercial unit at Colorado Ute's Craig Station. They also have a demonstration system operating at Pacific Power and Light's Jim Bridger Station. Meanwhile, fundamental research work is continuing at their Alliance Research Center (ARC).

Research and Development

Babcock and Wilcox feels that dry scrubbing technology has been adequately demonstrated on the pilot scale, at least for low sulfur coals, and there is little need for further demonstration programs. However, some development work is continuing at Jim Bridger Station (Figure 3-1) but will end by Fall 1980. Several sorbent types are being tested on this unit including soda ash, waste soda liquor (from FMC's soda ash plant at Green River), and lime. B&W, however, does not consider sodium to be the choice sorbent for dry systems because of the high reagent cost and waste disposal problems. The Jim Bridger demonstration plant includes a 120,000 acfm reactor with six Y-Jet air atomizing nozzles followed by a 6,000 acfm ESP and a nominal 3,000 acfm baghouse in parallel. Table 3-1 shows the specifications of the Jim Bridger System. The results of these demonstration tests will be presented by B&W at the FGD symposium in Houston in October 1980.

Fundamental research work is continuing at the ARC's 1500 acfm pilot unit. The objective of this research is better characterization of the dry scrubbing process including investigation of lime reactivity, slaking methods, reaction mechanism, degree of atomization, temperature relationships, reactivity of different ashes, and reactor performance with a fabric filter versus an ESP. B&W feels that some other areas that need exploration in the field are mechanical problems, wear characteristics, controllability, and methods of ash reinjection.

Babcock and Wilcox discussed some of the results of their fundamental research work in a paper presented to the American Power Conference in April 1980. Three reaction periods were postulated to exist within the life of the lime slurry spray during which aqueous phase SO_2-lime reactions can proceed. First is the constant rate period, second is the falling rate period, and third is the equilibrium (moisture) period (i.e., evaporation of water from the slurry droplet at a constant rate; evaporation of water at a falling rate by diffusion, and no evaporation of residual moisture). It was concluded that the first reaction period, the constant rate period, was not the predominant zone for SO_2 absorption. Beyond that point, modeling the SO_2 removal process was thought to be more difficult and the diffusion of SO_2 to the reaction zone was not quantified. However, work was in progress to develop mathematical models describing the SO_2 absorption process during all three periods.

The interactions among important parameters affecting SO_2 absorption during the last two periods (falling rate and equilibrium) were also identified in the B&W paper. During the falling rate period, SO_2 absorption was proposed to benefit by:

- Large mass transfer area via
  - fine atomization
  - high lime flow rate

TABLE 3-1. JIM BRIDGER STATION SYSTEM SPECIFICATIONS

Reactor Specifications	
Type	Horizontal
No. of atomizers	6
Atomizer type	Y-Jet air atomizing
Flow Volume	120,000 acfm
Draft loss	1.5 in. WG
Reactor retention time	6 sec
Reactor flue gas velocity	5 ft/sec
ESP Specifications	
Gas volume	6,000 acfm
Gas velocity	4.7 ft/sec
Specific collection area	141 ft^2/1000 cfm
No. of fields	3
Baghouse specifications	
No. of compartments	3
Bags per compartment	5
Bag diameter	11.5 in.
Bag length	30 ft. to 36 ft.
Gas flow	2670 acfm for 30 ft. bags 3210 acfm for 36 ft. bags
Air-to-cloth-ratio	2:1 ft/min

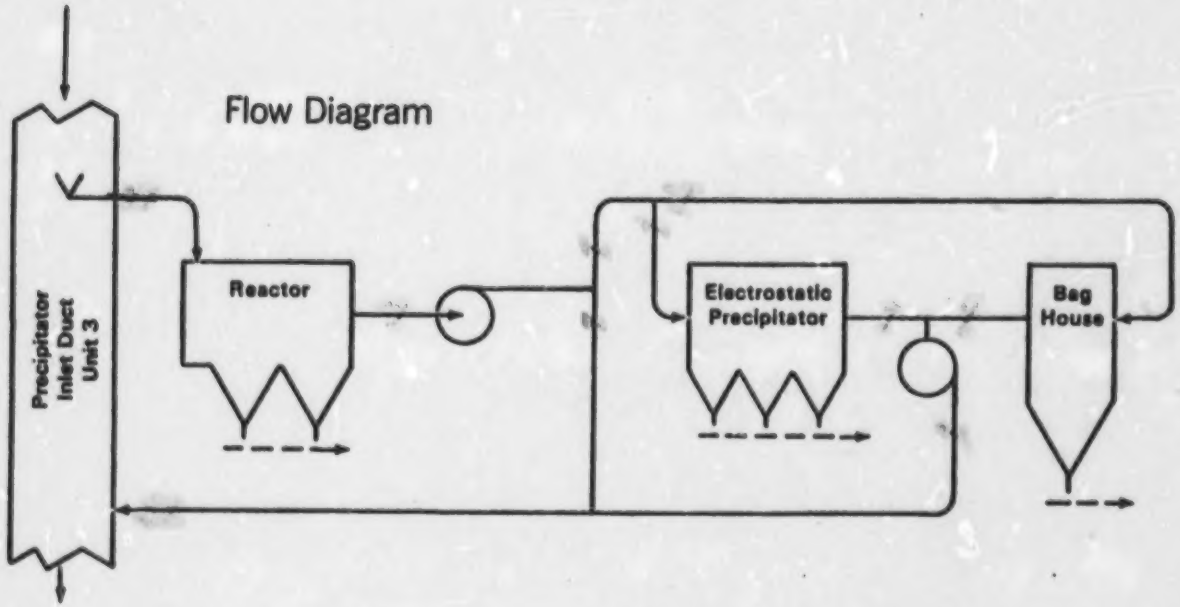

Figure 3-1. Jim Bridger Station Flow Diagram

- Long evaporation (reaction) period via
  - high percent solids
  - coarse atomization
  - close approach to saturation

During the equilibrium period, SO_2 control was proposed to benefit by:

- Large total surface area via
  - fine atomization
  - good slaking
  - high lime flow

- High humidity via
  - close approach to saturation

Whether the fundamental reactions between SO_2 and lime occur as gas-solid reactions or as ionic reactions in an aqueous medium can have a great influence upon the theoretical limit to which the lime can react. Specifically, because the gas-solid reaction takes place at the surface of the lime particle, the reaction products become part of the particle surface. After the lime surface has become completely coated with reaction products, the unreacted lime in the interior of the particle is not available for further reaction.

Examination of the dry scrubber product with a scanning electron micrograph revealed the existance of many free-standing ionic crystals of $CaSO_3 \cdot \frac{1}{2} H_2O$ and $CaSO_4 \cdot 2 H_2O$. B&W argued that if these crystals were formed as a result of gas-solid reactions, they would be more or less embedded into the surface of the lime particle and would be at least one order of magnitude smaller in size. Therefore, it was indicated that aqueous ionic reactions must predominate. It should be noted that other sources have suggested gas-solid surface reactions (Section 3.2).

Another point made by B&W was that although good atomization does not influence the SO_2 removal rate greatly for the first two reaction periods, fine atomization is important as it relates to improved SO_2 absorption during the third or equilibrium period. An equally important need for good atomization in a spray dryer concerned entrainment and dispersion. More specifically, unless the spray becomes, and remains, dispersed in the reactor so that intimate contact between the drying agglomerates of lime and flue gas can be maintained throughout the reactor, good lime utilization will not be possible.

Commercial Systems

Construction on Laramie River System (Figure 3-2) is proceeding on schedule and is expected to be complete by July 1, 1981. Initial operation is planned for November 1981, and commercial operation is expected to begin on April 1, 1982. This system consists of four reactors each followed by an electrostatic precipitator. Normal operation requires the use of only three

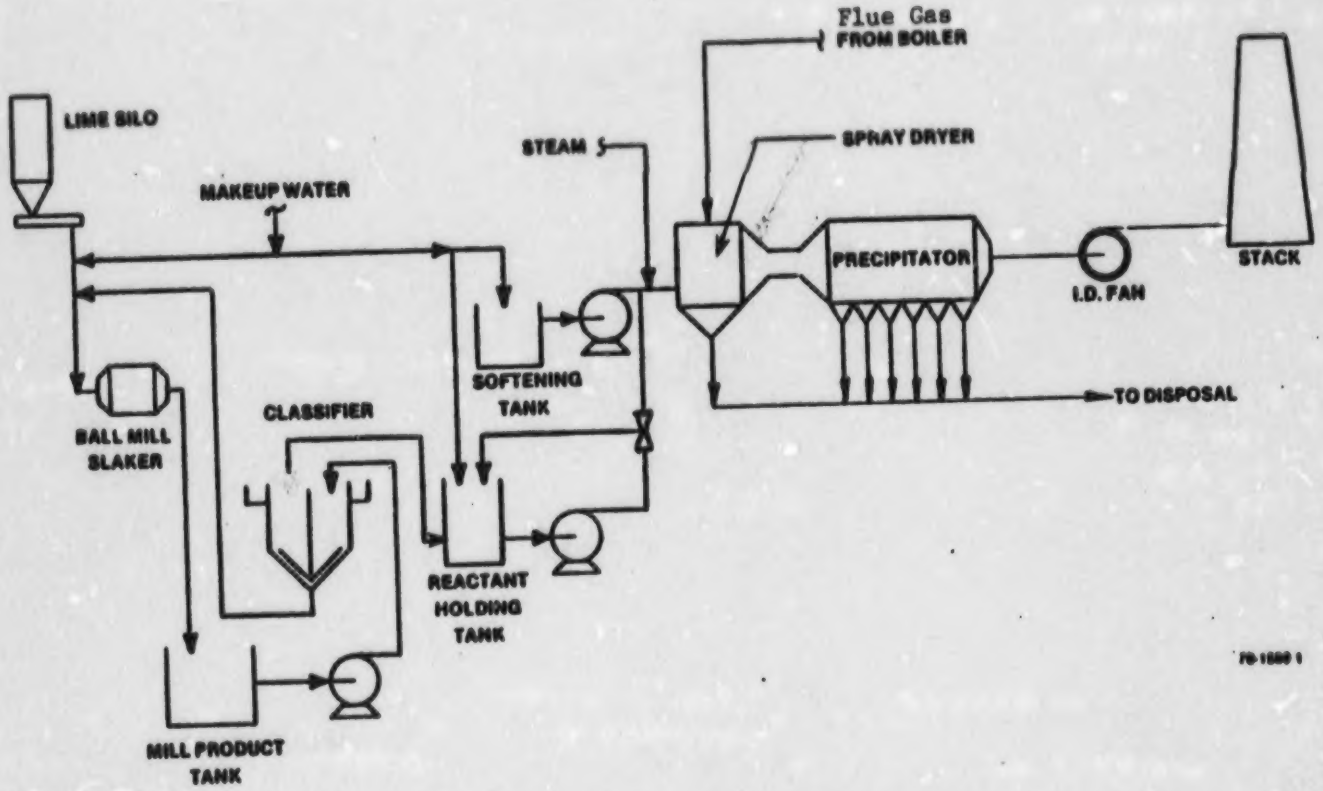

Figure 3-2. Laramie River Station flow diagram.

reactors, the fourth being a spare. The design SO_2 removal efficiency is 85 percent.

B&W has also been awarded a contract by Colorado Ute Electric Association for a commercial scale dry scrubbing system to be installed at Craig Station. Because of Colorado Ute's specification, this system will use a baghouse instead of an ESP. The reactor design, however, is similar to that being installed at Basin Electric's Laramie River Station (12 Y-Jet nozzles in three rows of four nozzles each). The Craig system and the Laramie River system both have 33-1/3 percent excess capacity and fully automatic process control requiring only one operator. The 447-MW system at Craig has a design SO_2 removal efficiency of 87 percent with stack emissions of 0.2 lb/10^6 Btu or 850 lb/hr. The design particulate removal efficiency is 99.82 percent with 0.03 lb/10^6 Btu or 130 lb/hr stack emissions. Inlet gas temperature will be 250°F. This dry scrubbing system will use a ball mill slaker and has provisions for solids recycle. The recycle stream, however, will not pass through the slaker since tests conducted by B & W have shown milling of recycle solids to have no effect on the system performance. Table 3-2 shows the coal and ash analyses and the system performance and design conditions for Colorado Ute's Craig Station dry FGD system.

TABLE 3-2. CRAIG STATION DRY FGD SYSTEM SPECIFICATIONS

Approx. coal analysis by wt.			Approx. ash analysis by wt.		
	Coal A	Coal B		Coal A	Coal B
Carbon	59.69%	52.42%	Lime (CaO)	6.35%	9.36%
Hydrogen	4.13%	3.63%	Magnesia (MgO)	1.77%	2.84%
Sulfur	0.40%	0.70%	Sulfur trioxide(SO_3)	4.45%	7.86%
Moisture	14.00%	16.00%	Sodium oxide(Na_2O)	2.50%	6.00%
Ash	8.00%	14.00%	Silica(SiO_2)	53.57%	43.25%
Oxygen	12.43%	12.16%	Misc.	31.36%	30.69%
Misc.	1.35%	1.09%			
	100.00%	100.00%		100.00%	100.00%
Btu/lb	10,250	8,950	Coal B - Design coal.		

System performance and design conditions	
SO_2 removal efficiency	87%
SO_2 emission from stack	0.2 lb/10^6 Btu or 850 lb/hr
Particulate removal efficiency	99.82%
Particulate emission from stack	0.03 lb/10^6 Btu or 130 lb/hr

Future Plans

Currently 20 to 25 percent of B&W's Fossil Power Division's pollution control efforts are concentrated on dry scrubbing. All of this effort is geared toward utility applications since B&W does not intend to bid for industrial applications. They feel that the fuel costs for most industries is a small portion of the total product cost and, therefore, a simpler solution would be to use good mechanically cleaned coal. Also, B&W plans at the present time to bid only for low sulfur Western coal applications.

Information Sources

Kelly, M.E. and Shareef, Syed. Meeting Notes at B & W, Barberton, Ohio, June 19, 1980.

Downs, W. et al. "Control of SO_2 Emissions by Dry Scrubbing". (Presentation at American Power Conference, Chicago, Illinois. April 21-23, 1980.)

3.2 BUELL/ANHYDRO AND EPA/BUELL

Address: Buell Emission Control Division
Envirotech Corporation
200 North Seventh Street
Lebanon, Pennsylvania 17042

Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Contact for More Information:

Research Projects - William T. Langan
Manager, Systems & Application Engineering
(717) 272-2001

T.G. Brna
EPA Project Officer
(919) 541-2683

Commercial Activities - Mr. Lloyd Hemenway
Buell Emission Control Division
(717) 272-2001

Background

Buell, a division of Envirotech Corporation, has two dry FGD efforts underway. One is Buell's in-house development of a dry injection/baghouse collection system which would use a Buell bag collector. In the other, Buell is working with Anhydro, a Copenhagen-based spray dryer company, to develop a spray dryer/baghouse system. Test work on both systems, funded by EPA, has been conducted at the City of Colorado Springs' Martin Drake Station.

Research and Development

EPA-funded test work on a 4500-acfm dry injection/baghouse system at the City of Colorado Springs Martin Drake Station was started in late October 1979. The test work investigated three sodium-based sorbents: nahcolite, raw trona ore, and upgraded trona. The parametric testing varied stochiometric ratios (0.7, 1.0 and 1.5) and inlet SO_2 concentrations (300 to 600 ppm). The fuel used in the Martin Drake unit is a Colorado bituminous coal with a higher heating value of about 12000 Btu/lb and a sulfur content of from 0.3 to 0.7 percent. The nahcolite used in the tests was obtained from a Bureau of Mines pilot shaft sunk in a Colorado nahcolite/oil shale deposit near Denver. The nahcolite from this mine will be made available for government and industry dry FGD test work. This pilot shaft is currently one of the few available sources of nahcolite. Trona and upgraded trona (90 percent $NaHCO_3$) is being supplied by Lake Minerals Corporation out of Owens Lake, California. A final report on this dry injection work will be issued in late 1980.

Buell is also participating in EPA-funded waste disposal studies through subcontract to Battelle-Columbus Laboratories. The major process to be studied is sintering of the dry sodium-based product, based on the Sinterna process (patented by Industrial Resources, Inc.) and tests should be completed at the end of 1980.

In another research program, Buell and Anhydro are developing a dry FGD system with a spray dryer and baghouse. Initial work with both lime and soda ash sorbents was done at Anhydro's Copenhagen facility with a 3000-acfm spray dryer. Presently, EPA-funded testing is being conducted on a 8500-acfm spray dryer/baghouse system at the Martin Drake Station. The spray dryer, supplied by Anhydro under an exclusive technological agreement, is a 12-ft diameter reactor equipped with a centrifugal atomizer. Sorbents being tested include lime, limestone, and crude trona. Adipic acid addition with lime and limestone is also being investigated for both dry and wet recycle. The spray dryer/baghouse system was started in December 1979, and tests will be run for 6 months to a year. Performance data from the pilot system will be used to evaluate the sorbents as well as providing a basis for a full scale system design.

A detailed technical paper on the Buell/Anhydro spray dryer/baghouse system appeared in the December 1979 issue of the Air Pollution Control Association Journal. The article developed a qualitative model for optimizing the SO_2 absorption reaction as a function of the various operating parameters based on over 300 pilot plant tests. Through x-ray analysis, it was shown that the total reaction can occur in two phases: a first phase where large numbers of solid $Ca(OH)_2$ particles are free to move in a liquid phase and the rate of $Ca(OH)_2$ diffusion through the formed calcium sulfite appears to control the rate of reaction, and a second phase where particles form a porous body and the reaction depends on pore diffusion for completion.

Buell displayed a scale model of a 20,000 acfm lime-based spray dryer/baghouse system at the American Chemical Society Chemical Show in New York, December 3-5, 1979. They also presented a technical paper on the operation and maintenance of a SO_2 spray absorber system at the APCA Conference in March 1980 and will present a technical paper at the October 1980 FGD Symposium sponsored by EPA.

Commerical Status

At this point, Buell's top priority is the completion of test work on the spray dryer and dry injection systems at Martin Drake. Buell has invited several architect-engineer (A-E) firms to visit the facility. Buell plans to rely heavily on presentations to A-E's and utilities in marketing their spray dryer system.

The Buell/Anhydro joint venture has submitted a number of budgetary prices to utilities and industries for spray drying systems.

Information Sources

Shareef, Syed. Telephone conversation with William Langan, Buell-Envirotech, July 14, 1980.

Getler, J.L., H.L. Shelton and D.A. Furlong. "Modeling the Spray Absorption Process for SO_2 Removal". Journal of the Air Pollution Control Association", December 1979, Vol. 29, No. 12. p 1270.

3.3 COMBUSTION ENGINEERING

Address: Combustion Engineering Inc.
P.O. Box 7462-A
Birmingham, Alabama 35223

Contact for More Information: Kal W. Malki
Environmental Systems Division
(205)967-9100

Background

In June 1978, Combustion Engineering (C-E) completed a detailed examination of dry scrubbing technology that included a technical and economic evaluation of a conceptual design of a dry scrubbing system for a 600-MW coal-fired boiler. They concluded that dry scrubbing was a viable flue gas cleaning alternative for boilers firing low sulfur coals and that the most promising process option was the use of lime additive without recycle. C-E decided that a pilot plant program would offer the most expedient means of developing design capabilities.

Research and Development

As a result of the above decisions, a pilot plant research and development program began in February 1979. In July 1979, construction of a dry scrubbing pilot plant was completed at Northern States Power Company's Sherburne County Generating Station in Becker, Minnesota. In this testing, the reactivity of alkaline fly ash constituents on additive stoichiometry and SO_2 removal was investigated.

The pilot plant treated a flue gas stream extracted from the air heater outlet of Unit 1 at the Sherburne County Generating Station. The fuel fired was Sarpy Creek Coal (1.0% S, 10.8% ash, 8300 Btu/lb). The pilot plant consisted of a 20,000 acfm dry SO_2 absorber, a 7000 acfm electrostatic precipitator, and a 1500 acfm fabric filter. The lime preparation system included a storage tank and a transfer tank. Hydrated lime, pulverized to 90 percent through 325 mesh consistency, was pneumatically injected below the water level in the lime storage tank. A schematic flow diagram is shown in Figure 3-3.

With once-through testing, 70 percent SO_2 removal was achieved at stoichiometric ratios of near 1.0. Most of the SO_2 removal took place across the spray dryer, with only 3 to 9 percent removal in the fabric filter. The removal efficiency was found to increase if solids recycle was used. Some of the results of the pilot tests are summarized in Table 3-3. The results also showed that removal can be improved 40 percent by merely lowering the absorber outlet temperature from 200 to 155°F. The outlet temperature can be reduced by increasing the liquid flow rate. This indicates that if the liquid-to-gas ratio is increased, the lime feed-rate could be reduced resulting in significant savings. The lower temperature, however, means a closer approach to saturation and a greater potential for incomplete evaporation and deposit build-up. Additionally, the results of the pilot tests also showed that the dropout in the absorber is between 20 and 25 percent of the total solids leaving the absorber.

Future Activities

The pilot study at Sherburne County indicated several areas that needed further investigation. C-E felt that optimization of design could only be realized through further development work. Construction of a second generation pilot plant at the Gadsden plant of Alabama Power was scheduled to be complete by early September 1980. The Gadsden plant was selected based upon the characteristics of the fuel fired.

The Gadsden plant will consist of a 20,000 acfm spray dryer and a 1000 to 1500 acfm fabric filter. Parameters to be tested include effects of stoichiometric ratio and recycle. High sulfur conditions (up to 2000 ppm) will be simulated and lime will be the primary sorbent. In addition, waste products will be characterized to determine practical means of handling and disposal. These tests are expected to be conducted over a 6-month period. However, the test facility will remain intact for any future tests.

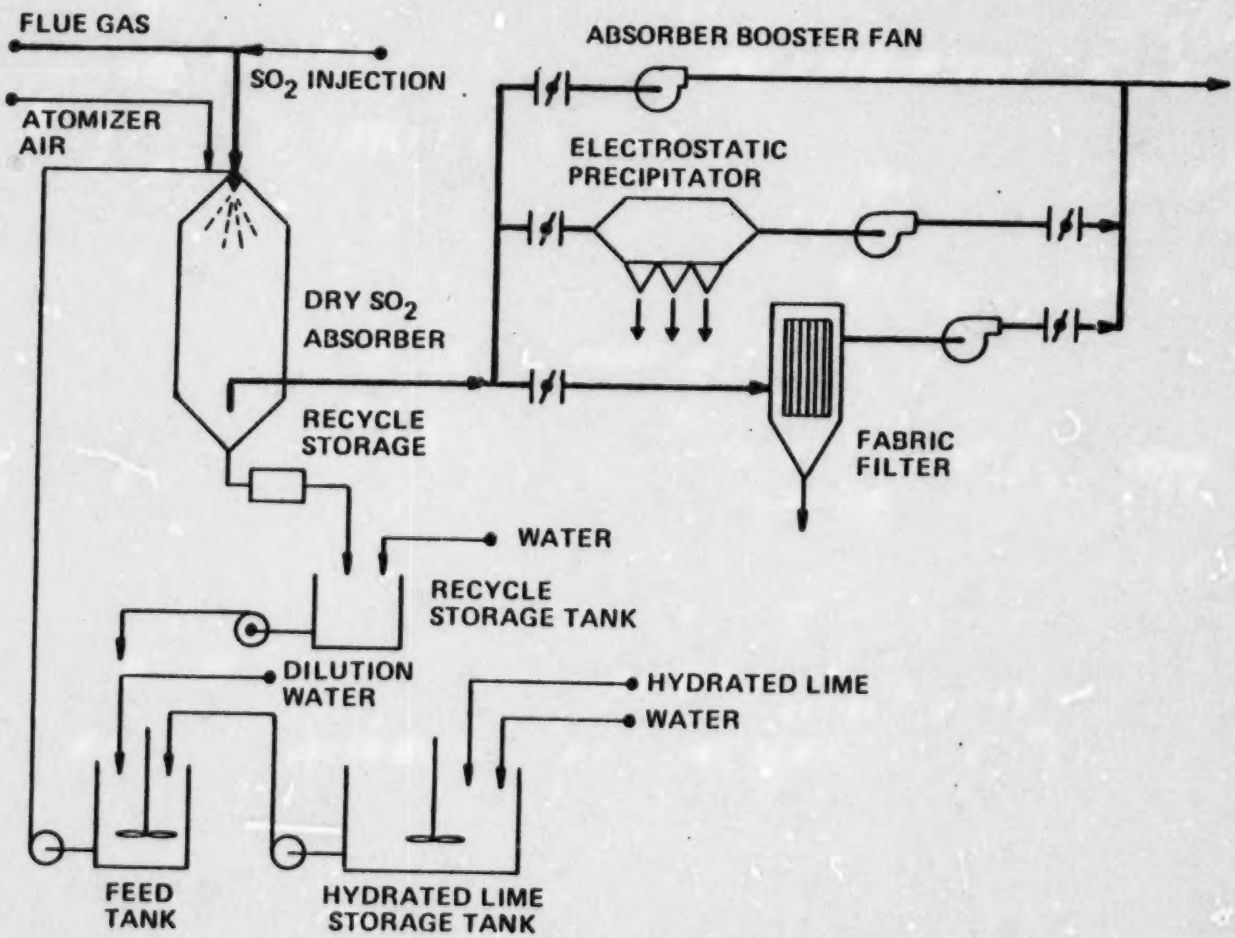

Figure 3-3. Schematic flow diagram of C-E's pilot plant at Sherburne County Generating Station.

TABLE 3-3. PILOT PLANT TEST RESULTS FROM SHERBURNE COUNTY GENERATING STATION

Test Number	Inlet SO_2 Conc. (ppm)	Temperatures In (°F)	Temperatures Out (°F)	Absorber Gas Vel. (ft/sec)	Recycle Ratio [a] (lb/lb)	Stoich. Ratio (mol/mol)	SO_2 Removal Absorber (%)	SO_2 Removal Total Syst. (%)
1	720	269	165	4.6	0	1.4	70	75
2	1120	261	170	4.6	0	1.3	68	73
3	720	268	170	4.6	0	1.5	85	89
4	620	303	173	4.6	0	1.3	73	76
5	660	312	178	4.6	0	1.1	67	77
6	750	300	170	4.6	0	1.8	77	80
7	750	293	174	4.6	0	1.1	68	72
8	600	309	172	4.6	0	1.4	77	86
9	600	307	166	4.6	0	1.4	88	92
10	635	312	180	4.6	0	1.8	75	79
11	1050	323	203	4.6	0	2.2	68	73
12	690	312	168	4.4	0	1.4	94	—
13	675	295	198	4.6	0	1.6	70	76
14	500	305	180	4.0	0	1.4	85	—
15	600	300	175	4.0	0	1.0	74	77
16	680	300	185	4.0	0	1.0	67	70
17	620	300	175	4.0	0.5:1	0.85	70	73
18	625	310	174	4.0	0.75:1	1.2	79	82
19	680	305	172	4.0	1:1	1.4	86	88
20	600	302	171	4.0	1:1	1.7	85	87
21	1250	310	178	4.0	0	1.3	72	80
22	1270	302	173	4.0	0	1.3	76	86
23	1310	298	171	4.0	0	1.3	77	85

[a] No definition of recycle ratio specified in the literature.

Information Sources

Shareef, Syed. Telephone conversation with Kal Malki, C-E, August 18, 1980.

Martin, J.R. et al. "C-E Dry Scrubber Systems: Application to Western Coals." (Presented at American Power Conference, Chicago, Illinois. April 21-23, 1980.)

3.4 DOE/GRAND FORKS ENERGY TECHNOLOGY CENTER

Address: Grand Forks Energy Technology Center
P.O. Box 8213
University Station
Grand Forks, ND 58201

Contact for More Information: Harvey Ness
Grand Forks Energy Technology Center
(701)795-8000

Background

Grand Forks Energy Technology Center (GFETC) has been conducting research on dry injection systems on the 200-scfm scale, comparing nahcolite and trona sorbents. Parameters investigated include inlet SO_2 concentration, inlet gas temperature, bag materials, air-to-cloth ratios, and the sequencing of sorbent addition and bag cleaning cycles.

Research

Dry injection test work on the 200-scfm scale has been completed. Data are now being compiled and a final report is expected by September 1980. Tests were performed to optimize performance with both trona and nahcolite. Tentative results show close to 90 percent utilization (based on NO_x and SO_2) for both sorbents. Low sulfur western coals were burned resulting in inlet SO_2 concentrations of 650 to 1100 ppm. Parameters tested included gas temperature at injection point, baghouse temperature, stoichiometry, SO_2 level, and particle size of dry material. No operational problems were encountered, but it is felt that tests have to be conducted on a larger scale to draw definite conclusions about process characteristics. GFETC is also conducting waste disposal studies but no results are available at this time.

Future Research Plans

Major components of a 150 scfm pulse-jet baghouse were scheduled to be delivered to GFETC labs in mid-July 1980. Construction of the unit is expected to begin in September 1980. This baghouse will be used exclusively

for dry injection tests (the present baghouse is also used for particulate characterization studies). Both trona and nahcolite will be tested while varying parameters such as temperature, residence time (air-to-cloth ratio), and sorbent stoichiometry. Tests will be conducted at temperatures up to 800°F.

In addition, GFETC will be involved with the spray dryer/baghouse FGD system being constructed at Otter Tail Power's Coyote station. GFETC will conduct sampling and monitoring for particulate and SO_2 removal efficiencies under typical operating conditions at Coyote Station. This FGD system is scheduled to start up in the Spring of 1981. Grand Forks has also conducted in-house test work involving sodium recovery from spent sorbent/fly ash for reinjection into both spray dryer and dry injection systems.

Information Sources

Shareef, Syed A. Telephone conversation with Harvey Ness, GFETC. June 3, 1980.

Shareef, Syed A. Telephone conversation with Harvey Ness, GFETC. July 23, 1980.

3.5 DOE/PITTSBURGH ENERGY TECHNOLOGY CENTER

Address: Pittsburgh Energy Technology Center
4800 Forbes Road
Pittsburgh, Pennslyvania 15213

Contact for More Information: Richard Demski
Pittsburgh Energy Technology Center
(412) 675-5730

Background

DOE's Pittsburgh Energy Technology Center (PETC) has had a program underway for several months to evaluate dry injection of various sorbents. They have a 500 lb/hr coal furnace that provides the flue gas for their testing.

Research

PETC's initial testing has focused on dry injection systems. System parameters that were evaluated included sorbent type, stoichiometry, sorbent feed mechanism, and sorbent particle size. Four sorbents have been tested: sodium carbonate, sodium bicarbonate, nahcolite, and trona. Dry injection testing is now complete and a final report is due in October 1980.

Commercial sodium bicarbonate was found to be the most reactive sorbent. In addition, nahcolite and trona showed different behavior in the sense that while different batches of nahcolite produced the same removal results under the same conditions (e.g. composition, stoichiometry, etc.) trona did not. In other words, two different batches of trona with identical composition, when tested under identical operating conditions, did not produce identical SO_2 removal efficiencies.

PETC's test work also confirmed that at the same stoichiometric ratio a given sorbent achieved lower SO_2 removal for a high sulfur (3% S, West Virginia) coal than for a low sulfur (1.6% S) Pittsburgh coal. Also, for the same coal, a lower stoichiometric ratio resulted in lower SO_2 removal.

Future Research

Tests are scheduled to begin soon on a spray dryer system and are expected to be conducted over the next year and a half. Sorbents to be tested are primarily Na_2CO_3 and lime.

Information Source

Shareef, Syed. Telephone conversation with Richard Demski, PETC, August 7, 1980.

3.6 ECOLAIRE

Address: Ecolaire Systems, Inc.
Two Country View Road
Great Valley Corporate Center
Malvern, Pennslyvania 19355

Contact for More Information: Carl Newman
Vice-President for Engineering
(215) 648-8600

Background

Ecolaire has constructed a mobile pilot plant for demonstration of a spray dryer/baghouse FGD system. The unit uses an Ecolaire-modified Niro atomizer spray dryer and an ICA four-section baghouse with 12-in. diameter by 36-ft length bags.

Research and Development

Ecolaire is engaged in a development project using their Mobile Demonstration Unit (MDU) rated at 10,000 acfm. The MDU is installed on Unit No. 1 at the Gerald Gentleman Station of the Nebraska Public Power

District at Sutherland, Nebraska. The unit is comprised of a spray dryer fabric filter, chemical laboratory, ancillary equipment including induced draft fan controls and instrumentation, ash collection and removal system, and facilities for preparation and feeding of reagents.

To date, Ecolaire has conducted a series of parametric tests in which the following parameters were varied over the indicated ranges:

Reactor Inlet Temperature	210°F to 305°F
Reactor Approach to Saturation Temperature	Low 20's to 70°F
Reactor Inlet Stoichiometric Ratio	0.5 to 0.6
SO_2 Inlet Concentration	300 ppm to 1000 ppm
Reactor Top Dish Speeds	Proprietary

Removal performance of various reagents, including hydrated lime, pebble lime, a high calcium lime, dolomitic lime and sodium carbonate, has been investigated. The reactivity of recycled material has been tested and compared to fresh sorbent.

In addition to the parametric studies, useful data have been obtained about baghouse performance. Future work at the present site will include testing of a two-fluid nozzle atomizer and an extension of the test range of flue gas sulfur content. All test results are considered proprietary and are made available only upon the execution of a secrecy agreement.

Commercial Activities

Ecolaire has been placed on the bidder's list for a number of commercial inquiries for dry flue gas desulfurization. Ecolaire has responded to these inquiries and anticipates an award of a contract for a system to serve an industrial, coal-fired boiler during the third quarter of 1980.

In addition, Ecolaire has been awarded an engineering study for an industrial installation including a conceptual system design and the verification of the proposed reagent performance by testing of the reagent in the Ecolaire Mobile Demonstration Unit.

Finally, Ecolaire is very positive about the commercial future of the dry flue gas desulfurization process for treating combustion products from coal-fired industrial and utility boilers. Ecolaire believes that economic considerations limit the applicability of the dry scrubbing process to coals containing less than 2 percent sulfur as fired. However, where site specific conditions vary from those usually encountered, they believe this applicability limit can be extended to the area of 2.5 to 3 percent without technical difficulty.

Information Sources

Carl L. Newman, Ecolaire. Personal communication with Syed Shareef. August 7, 1980.

3.7 ELECTRIC POWER RESEARCH INSTITUTE

Address: 3412 Hillview Avenue
Palo Alto, California 94304

Contact for More Information: Richard Hooper
EPRI Project Manager, Arapahoe Office
(303) 936-7281

Background

EPRI's Air Quality Control Program is conducting research on technical aspects of a dry injection/baghouse system. Sorbents being investigated are nahcolite and trona. The laboratory scale test phase has been completed and a full-scale dry injection demonstration program at Public Service of Colorado's Cameo Station is in progress.

Research and Development

Laboratory scale studies were conducted by KVB, Inc. on an 800 scfm dry injection/baghouse system. A 0.45 percent S western coal was fired during the tests. Parameters investigated included:

- sorbent type (nahcolite, trona, commercial $NaHCO_3$),
- sorbent utilization,
- sorbent particle size,
- baghouse temperature,
- air-to-cloth ratio,
- cleaning cycle time for fabric filter,
- sorbent injection method (continuous, batch),
- flue gas temperature at injection point,
- predecomposition of nahcolite, and
- inlet SO_2 concentration.

Table 3-4 shows the results achieved with nahcolite and Table 3-5 presents the results of tests with trona. About 40 minutes were required to achieve maximum steady state SO_2 removal with nahcolite, causing removal to be dependent on cleaning cycle time. Steady state removal levels with trona, however, were reached almost immediately.

TABLE 3-4. RESULTS WITH NAHCOLITE - EPRI/KVB LAB TESTS

Stochiometric Ratio (moles Na fed/moles SO_2 in) 2	Injection Point Gas Temperature (°F)	SO_2 Removal (%)	Special Test Conditions
1.0	270	50	90 minute test period maximum removal 67%
1.5	270	70	
1.0	550	80	
1.0	800	60	
0.9	270	42	
0.9	270	42	
0.9	270	66	Precoat of bags with nahcolite

Note: Commercial sodium bicarbonate was found to behave generally like trona, but exhibited somewhat lower SO_2 removal.

TABLE 3-5. RESULTS WITH TRONA-EPRI/KVB LAB TESTS

Stochiometric Ratio (moles Na fed/moles SO_2 in) 2	Temperature (°F)	SO_2 Removal (%)	Special Test conditions
1.0	baghouse inlet (~270)	40	None
3.0	baghouse inlet (~270)	70	
2.0	baghouse inlet (~270)	50 to 62	
2.0	"elevated"	70 to 78	

With nahcolite, SO_2 removal at a given stochiometry increased as gas temperature at the injection point increased up to 550°F. Decreased removal was observed at 800°F. For both nahcolite and trona, removal increased as sorbent stochiometric ratio increased. (The stochiometric ratio was defined as the "actual sodium to sulfur ratio normalized by the sodium to sulfur ratio required to form sodium sulfate (Na_2SO_4)").

Precoating the bags with nahcolite increased SO_2 removal from 42 to 66 percent at a constant stochiometric ratio of 0.9. Variations in air-to-cloth ratio from 2 to 4 ft/min had no effect on SO_2 removal.

Demonstration

A full-scale dry injection demonstration program is being funded by EPRI and Public Service of Colorado. The tests will be conducted on the Cameo Station Unit 1 (22 MW) boiler. The objective is to demonstrate continuous 70 percent SO_2 removal and obtain data to determine the energy and nahcolite reagent costs. The system was designed by Stearns-Roger, Inc., and testing will be conducted by KVB, Inc.

Crushed nahcolite from a nearby pilot shaft will be pulverized and injected into the system between the existing mechanical collector and fabric filter. The maximum planned sorbent injection rate will likely require fabric filter operation modifications such as increased cleaning frequency and increased ash removal rate. No fabric filter hardware changes are planned.

The test work, already in progress and scheduled to be completed by November, will basically consist of four phases:

Phase I: Characterization of SO_2, SO_3, and particulate loadings.
Phase II: "Familiarization" tests to define system capability.
Phase III: Parametric testing to determine recommended operating parameters.
Phase IV: Continuous 1-week operation under normal plant conditions.

The SO_2 removal efficiency will also be evaluated as a function of nahcolite utilization and particle size, baghouse cleaning mode and frequency, and boiler load.

Information Source

"SO_2 Control by Dry Sorbent Injection." EPRI Journal. Palo Alto, California. June 1980. p 53.

3.8 ENERGY AND POLLUTION CONTROL, INC.

Address: Energy and Pollution Controls, Inc.
Subsidiary of Flick-Reedy, Inc.
7N015 York Road
Bensenville, Illinois 60106

Contact for More Information: Grant Hollett, Jr.
Energy and Pollution Controls
(312) 766-3400

Background

Development work on the Energy and Pollution Control (EPC) designed reactor was started in early 1978. This dry FGD reactor is intended for combination with a baghouse, resulting in a totally dry FGD system for industrial applications. The reactor is designed for cyclonic flow of flue gas near a hydraulically driven "slinger", which distributes dry hydrated lime in a direction countercurrent to the flue gas flow. Hydrated lime is fed to the slinger with a commercially available dry chemical feeder. Directly above the slinger is an air-operated eductor which captures and recirculates the lighter fraction of the partially spent sorbent. Below the reaction section of the reactor, a conical expansion reduces the flue gas velocity to allow dropout of heavy particulate matter before the gas flows to a bag collector. Gas velocities in ductwork to and from the reactor are typically 8 to 12 ft/sec. Velocities inside the reactor vary from approximately 25 ft/sec in the cyclonic section down to approximately 5 ft/sec in the expansion section.

Development work on the reactor used flue gas from a coal-fired (1.6 million Btu/hr) hot water boiler burning a 3.3 percent sulfur Illinois coal. Flue gas sulfur content varied from 1600 to 2300 ppm SO_2. Flue gas temperatures in the reactor varied from 350°F to 500°F, but temperatures to the downstream cartridge filtration device were limited to 350°F to protect the NOMEX cartridge. The speed of the slinger was not specified, due to patent considerations. Pressure drop across the reactor in all tests was less than 0.5 in. of water. SO_2 removal efficiencies varied from 45 percent to 95 percent at 0.8 to 3.0 times the theoretical stoichiometric ratio.

Commercial Status

EPC is concentrating its marketing efforts entirely on industrial applications. In May 1980, EPC ran a program of on-site pilot-scale tests for an unidentified customer in the brick manufacturing business. These tests were conducted with EPC's "totally dry" FGD reactor system followed by a NOMEX cartridge filter-type baghouse. SO_2 removal efficiency ranged from 38 percent to greater than 95 percent at inlet gas temperatures ranging from 100°F to 750°F with an inlet SO_2 concentration of about 4000 ppm. Higher removals were observed at the higher temperatures.

Particulate removal efficiency was greater than 99 percent. The dry lime cake on the bags was found to contribute to SO_2 as well as particulate removal. Pressure drop across the whole system (including the baghouse) was about 4 to 5 in. water. Based on the results of the pilot tests, EPC is currently involved with the preliminary design of a commercial scale (>100,000 acfm) totally dry FGD system for this client.

Notice of allowance has been received on the patent application for EPC's reactor system. The EPC is now conducting discussions with at least two other firms for licensing this system. The commercial emphasis is expected to be on high sulfur Illinois or similar mid-western coal. In addition, further test work may be conducted in 1981 on recycling of once-through material from the reactor.

Information Sources

Shareef, Syed. Telephone conversation with Grant Hollett, Jr. July 16, 1980.

3.9 EPA/BATTELLE - COLUMBUS LABS

Addresses: Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Battelle - Columbus Labs.
405 King Avenue
Columbus, Ohio 43201

Contact for More Information: J. H. Wasser
EPA Project Director
(919) 541-2476

Robert Giammar
Battelle
(614) 424-7701

Background

As part of an EPA-funded program to evaluate industrial coal-fired stoker boilers, Battelle developed a limestone/high sulfur coal pellet in an attempt to control SO_2 emissions. Initial tests were conducted in a model 20 bhp spreader-stoker boiler using a pellet with a Ca:S mole ratio of 7:1. Preliminary results indicated that 70 to 80 percent retention of the available sulfur in the fuel was achievable. However, the increased particulate emissions resulted in an opacity increase from the normal 4 to 7 percent up to 22 to 25 percent. Furthermore, these pellets did not have adequate strength to withstand the severe stresses of an industrial fuel-handling system. In an effort to overcome these problems, Battelle began development and testing of a 3.5:1 Ca:S pellet.

Research and Development

The newly developed pellet (Ca:S ratio of 3.5) has mechanical strength, durability and weatherability characteristics comparable to that of raw coal as shown in Table 3-6. Results from laboratory tests on 20 bhp model spreader stoker are given in Table 3-7. The pellets have demonstrated 60 to 80 percent retention of the available sulfur in the fuel. A high sulfur Illinois coal was used for these tests. The coal was ground to 100 percent through 20-mesh and 50 percent through 100-mesh. Ground limestone (-50 mesh) was added to the coal with a binder and the mixture was fed to a mill that produced 1/2 in. diameter by 3/4 in. length cylindrical pellets. Variations in sulfur capture were attributed to variations in bed temperatures, with sulfur capture tending to be reduced at higher bed temperatures (above 2300°F).

In addition to the model spreader tests, a 1-day check out test was conducted in December 1979 on Battelle's 25,000 lb/hr spreader stoker-fired boiler at the Columbus Lab facilities. The purpose of this test was to investigate combustion characteristics and sulfur retention capabilities of the lower Ca:S pellet as well as to determine the effects of the pellet on boiler operation. With regard to boiler operation, one preliminary hypothesis is that the limestone present in the pellet may result in higher ash fusion temperatures, thus helping to reduce the clinker formation tendency of the coal.

Initially, a cement binder was used for the higher Ca:S tests. Sulfur removal efficiency of about 75 percent was achieved. However, in the second series of tests, which were conducted using an organic binder and about half of the limestone used in the first test, the removal efficiency was found to be reduced to about 50 percent. This may be attributed to the fact that the bed temperature could not be controlled effectively and rose up to about 2600°F. Table 3-8 shows the sulfur retention and bed temperature variations with changes in boiler load.

A demonstration test was conducted during which 20 tons of the limestone/coal fuel pellets with a Ca:S ratio of 3.5 were fired in the 25,000 lb/hr spreader-stoker boiler in the Battelle steam plant. Two types of pellets were used: a lower density (0.9 to 1.2 gm/cc) pellet produced by Banner Industries using auger extrusion and a higher density pellet (1.4 gm/cc) produced by Alley-Cassetty Coal Company using a pellet mill. Both types of the pellets were fired under a variety of boiler conditions. Visual observations, criteria pollutants, and ash analyses were the basis for evaluation. During the demonstration tests, the pellet feed rate was maintained at approximately 1.5 tons/hr for a boiler load of 80 percent of design. Tables 3-9 and 3-10 summarize the results of this test.

TABLE 3-6. COMPARISON OF PHYSICAL PROPERTIES OF RAW COAL AND FUEL PELLET

Production Method	Pellet Formulation[a] Coal Type	Coal %	Limestone Type	Limestone %	Binder	Durability Index[b]	Compression Strength, lb	Weather Index[b]	Post Weathering Durability[b] Index	Post Weathering Strength, lb
Raw coal	Illinois #6	100	—	—	—	85 ± 2	74 ± 12	89 ± 1	75	58
Raw coal	E. Kentucky	100	—	—	—	85 ± 2	83 ± 22	94 ± 1	83	94
Raw coal	Lignite	100	—	—	—	77 ± 4	92 ± 22	80 ± 4	34	45
Raw coal	Rosebud	100	—	—	—	84 ± 2	50 ± 15	79 ± 2	20	68
Mill CPM lab	Illinois #6	70	Piqua	30	2% Allbond + 1% Polyco 2136	87	112	100	85	>112
Banner extrusion	Illinois #6	70	Piqua	30	1.5% Allbond 200 + 1% M-167 .01	94	84	100	62	60

(a) Water added as needed.

(b) Percent survival = 100 - percent fines.

Reference: Glasmar, Robert D. et al. See Information Sources at the end of this section.

TABLE 3-7. MODEL SPREADER STOKER EXPERIMENTS

Fuel	Ca/S	Production Technique	Measured SO_2, ppm	Predicted SO_2, ppm	Sulfur Retention, percent
Illinois No. 6	0	---	3700	3700	0
Cement-bound pellets	7	Pellet mill (cylinders)	1040	3700	72
Cement-bound pellets	3.5	Ditto	1220	3700	67
Methylcellulose-bound pellets	3.5	Ditto	1480	3700	60
Ditto	Ditto	Ditto	1260	3700	67
Ditto	Ditto	Briquettes	1780	3700	52
Ditto	Ditto	Auger extrusion (cylinders)	1370	3700	63
Ditto	Ditto	Disc (spheres)	Pellets did not have adequate strength		

Reference: Gissmar, Robert D. et al. See Information Sources at the end of this section.

TABLE 3-8. CHECKOUT TEST CONDITIONS AND RESULTS

Boiler load, percent full load	Bed temperature, F	Sulfur Retention, percent
64	2400	50
80	2560	48
85	2600	47

TABLE 3-9. EMISSION DATA SUMMARY FOR FUEL PELLET DEMONSTRATION

Load, #/hr	O_2, %	CO_2, %	CO, ppm	NO, ppm	SO_2, ppm	Smoke Opacity, %	CO at 3% O_2, ppm	NO at 3% O_2, ppm		Fuel N Converted, %	SO_2 at 3% O_2, ppm		Fuel S Emitted %	Particulates, $lb/10^6$ Btu
								Computed	Measured		Computed	Measured		
20,000	8.4	10.5	300	310	1600	20	420	2250	440	20	4100	2250	55	0.6

TABLE 3-10. SULFUR BALANCE FOR COMBUSTION OF COAL LIMESTONE PELLETS

Computed Fuel S In, $lb/10^6$ Btu	Emitted as SO_2 $lb/10^6$ Btu	Sulfur Retained In Bed Ash as SO_2, $lb/10^6$ Btu
7.4	4.1	3.3

As indicated in Table 3-9, the sulfur capture was 45 percent during the demonstration test. The greater sulfur retention of the earlier model spreader tests is attributed to the lower bed temperatures which were seldom higher than 2300°F. The bed temperatures during the demonstration tests were seldom less than 2500°F and as high as 2650°F. Additionally, with a pulsating ash discharge stoker, the fuel bed is violently disturbed. Ash can, therefore, be recirculated back into the hot zone. Thus, if sulfur is retained in ash at a lower bed temperature, it may be released when the ash is exposed to a higher temperature.

The Battelle steam plant boiler facility had a mechanical collector to control particulate matter. Depending on the ash and sulfur content of the coal, earlier experiments had shown that particulate loadings varied between 0.2 and 0.6 lb/10^6 Btu. Generally, for low S, low ash coals, particulate loadings were less than 0.3 lb/10^6 Btu. The particulate loading during the demonstration tests was 0.6 lb/10^6 Btu. This loading is not unusually high for a spreader stoker firing a 33 percent ash coal. The smoke opacity was 20 percent which would appear low for a particulate loading of 0.6 lb/10^6 Btu if the fly ash collected were for conventional stoker coal. However, the fly ash from pellet firing is about 50 percent more dense and considerably more coarse than from conventional coals. For equivalent mass loading, optical density varies inversely with particle size and density. Thus, the apparent discrepancy between smoke opacity and particulate loading is explained partially by laws of optics.

An economic analysis of the limestone/coal pellet process was also conducted by Battelle-Columbus. The results of this analysis is summarized in Table 3-11. This analysis considers costs related to raw materials, utilities, labor, and capital, including profit, interest and income tax. However, it does not consider the increased costs of firing the boiler. For example, because of the high ash content of the pellet, ash handling and disposal costs would be higher than for the low ash conventional coals. Based on 60 tons per hour product, with a composition of 65 percent coal, 30 percent limestone, and 5 percent portland cement, the total employed capital was found to be about $3.1 million and the annual cost about $6.2 million ($14/ton). These calculations were based on an operating schedule of 23 hours per day, 330 days per year. The cost estimates are expected to vary depending on the type of system used and whether the process may be integrated into a physical coal-cleaning preparation plant.

Additionally, bench-scale waste disposal studies conducted by Battelle have shown that the ash produced from combustion of the coal/limestone pellet does not exhibit the same acid-leaching characteristics as fly ash from straight coal combustion.

Future Activities

A 14-day test is scheduled to begin in November 1980 on General Motors' 60,000 lb/hr steam chaingrate stoker boiler at GM's Indianapolis plant. The test duration has been limited by pellet production capability and GM's operating considerations.

TABLE 3-11. SUMMARY OF LIMESTONE/COAL PELLETING PROCESS COSTS

Basis: 60 tons per hour product with 65 percent coal, 30 percent limestone, 5 percent portland cement
23 hours per day, 330 days per year
1380 tons per day, 455,400 tons per year of product

Fixed plant investment	$2,790,000
Working capital	80,000
Interest during construction	250,000
TOTAL EMPLOYED CAPITAL	$3,120,000

ITEM	Annual Costs, Dollars	Per Ton Pellets, Dollars
Raw Materials		
Limestone 18 tons/hr. 136,620 tons/year at $8/ton delivered	1,092,960	2.4
Pregelatin cornstarch 1.2 tons/hr, 9100 tons/year at $20/ton delivered	1,138,500	3.0
latex emulsion, 1.2 ton/hr, 9100 tons/year at $150/ton delivered and		
Utilities		
Process water 12 tons/hr (48 gpm), 21.9 MM gallon/year at $0.2/M gal	4,400	0.01
Fuel oil 32 MM Btu/hr, 243 trillion Btu/yr at $3/MM Btu	728,600	1.60
Power 75 percent of 1917 kW or 1440 kW at $0.035/kWh	382,500	0.84
Diesel fuel 5 gph, 37,950 gallon/year at $0.80/gal	22,800	0.06
Labor Related		
Direct labor — 7 operators @ $8/hr plus 25 percent payroll burden ($10/hr total); staffed 365 days/yr	613,200	1.30
Supervision — 15 percent of direct labor	91,980	.20
Overhead — 50 percent of direct labor and supervision	306,500	.70
Capital Related		
Maintenance — 6 percent of fixed plant investment	167,400	0.37
Special pelletizer maintenance at $0.30/ton plus	387,100	0.85
$0.55/ton die and rollers	3,300	0.01
Front-end loader maintenance at $0.22/hr per machine	41,850	0.09
Taxes and insurance — 1.5 percent of fixed plant investment	250,000	0.56
Depreciation — 11 year, straight line on fixed plant investment	936,000	2.05
Profit, interest, income tax — 30 percent of total employed capital	$6,167,100	14*
TOTAL		

Reference: Glammer, Robert D. et al. See Information Sources at the end of this section.
* Does not include cost of coal.

Two or three short runs were planned for mid-August prior to full-scale operation. The results of the past tests and the upcoming 30-day full-scale demonstration test will be evaluated to determine their potential impact on the nation's energy supply and pollution standards.

Information Sources

Shareef, Syed. Telephone conversation with J.H. Wasser, EPA. June 3, 1980.

Shareef, Syed. Telephone conversation with J.H. Wasser, EPA. June 18, 1980.

Giammar, Robert D. et al. "Limestone/Coal Pellet - A Viable Method to Control Emissions From Industrial Boilers." (Presentation at the 73rd Annual Meeting of the Air Pollution Control Association, Montreal, Quebec. June 22-27, 1980.)

3.10 EPA/ENERGY AND ENVIRONMENTAL RESEARCH CORP. (EERC)

Address: Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Contact For More Information: Blair Martin
EPA Project Director
(919) 541-2235

Background

EERC conducted a preliminary feasibility study as part of a program to test EPA's concept of limestone injection into a low-NO_x burner for SO_2 removal. In this process, limestone is mixed and pulverized with coal prior to combustion and fired through a B&W low-NO_x burner. Sulfur contained in the fuel reacts with the limestone present to form calcium salts which are collected with the fly ash emitted from the boiler.

The B&W low-NO_x burner system consists of two physically isolated combustion zones: a fuel-rich water-cooled primary combustion furnace and a secondary furnace where combustion products from the first furnace mix with the air necessary to complete combustion. EERC has measured the retention of sulfur resulting when limestone or trona is mixed with coal prior to combustion in the burner. The effectiveness of alkali addition to this type of burner is apparently related to the lower flame temperature resulting from the two-stage combustion as compared to conventional combustion. The lower temperature keeps the particles from approaching their melting temperatures, which can cause glazing of the surface of the reagent particles and result in relatively unreactive particles.

EERC has noted that sulfur retention effectiveness is dependent upon good mixing of the reagent with the coal. They have found that adding reagent to the coal prior to passing the coal through the pulverizer substantially improves SO_2 removal. The pulverizer, which is designed for 75 percent

minus 200 mesh, is believed to promote good mixing between the reagent and coal. EERC has also noted that sulfur retention can be greatly influenced by combustion conditions in general.

Research and Development

As a result of these initially favorable performance data, EPA decided to conduct tests on a range of combustor sizes: 70,000 Btu/hr, 1 million Btu/hr, 10 million Btu/hr and 50 million Btu/hr. These tests are expected to lead to results over more realistic full-scale temperature ranges.

The 70,000 Btu/hr bench-scale unit has been tested for flame and flue gas characteristics in the absence of sorbent. Full parametric testing will be conducted on a low sulfur Utah bituminous coal (0.7% S) and a German brown coal (0.35% S as received). These coals are similar in nature with respect to combustion characteristics. Tests are planned on a wide variety of sorbents including different types of limestone and lime. There is a possibility that some sodium-based sorbents may also be tested, although lime-based sorbents are higher in priority. After the completion of these tests, the mid-sized unit (1 million Btu/hr) will become operational in late 1980.

Information Sources

Shareef, Syed. Telephone conversation with Blair Martin, EPA. June 17, 1980.

3.11 FLAKT, INC.

Address: 1500 East Putnam Avenue
Old Greenwich, Connecticut 06870

Contact for More Information: James Farrington
Product Manager
Gas Absorption Systems
(203) 637-5401

Background

Flakt's capabilities in the dry FGD area are based on experience in four allied technologies: conditioning towers and atomization, dust collection, wet FGD processes, and dry adsorption. With the experience gained from these allied technologies, Flakt initiated its dry FGD development program in 1978.

The laboratory development of Flakt's dry FGD process began with various theoretical models and qualitative comparison of alkalies. Later, a 300 acfm bench-scale unit in Flakt's laboratory in Vaxjo, Sweden, extended this qualitative evaluation to a larger scale. This testing confirmed some of the theoretical predictions that had resulted from the earlier kinetic and chemical thermodynamics research.

Since the quantitative transfer of the bench-scale results to commercial or even pilot plants is impossible due to the vastly different atomization characteristics that result from scale-up, a nominal 10,000 acfm reactor tower was tested in Vaxjo to study atomization as well as SO_2 absorption. The use of a full-scale nozzle in this test tower permitted a scale-up with a modular approach.

Research and Development

Flakt has two pilot plant programs, one in Denmark and one at Pacific Power & Light's Jim Bridger Station.

A 10,000 acfm pilot unit has operated since January 1980 at the Asnaes Power Station in Kalundburg, Denmark. After removal of 60 to 75 percent of the flyash in an upstream mechanical collector, the flue gas flows through the spray dryer reactor where it co-currently contacts the lime slurry absorbent. The lime slurry is atomized with air in a two-fluid nozzle. At a SO_2 inlet loading of 800 ppm, 50 percent of the SO_2 is removed in the spray dryer. A high-ratio pulse jet fabric filter provides additional alkali/SO_2 contact and reportedly removes an additional 30 to 40 percent of the total SO_2. The FGD reaction products and the residual flyash are collected in the fabric filter which operates at a pressure drop of 6 in. H_2O. The fabric filter contains 72 16-ft length bags. The Asnaes pilot plant also incorporates a recirculation system to internally recycle the reaction products. Lime is the sorbent currently being used at this plant which burns low alkaline coals from Poland, South Africa, and the Eastern United States. The coal sulfur content varies between 0.5 and 1.6 percent, resulting in an inlet SO_2 concentration of 600 to 1300 ppm.

The Jim Bridger plant, a 2000 MW generating station jointly owned by Pacific Power and Light Company and Idaho Power Company, is the site of Flakt's other dry FGD pilot program. Testing has been in progress since March 1980. Since layout restrictions may be more limiting than process requirements at some locations, two alternative reactor configurations, vertical and horizontal towers, are being evaluated. A slipstream of flue gas is extracted from an existing ESP inlet duct. The flue gas, which is at a relatively low temperature (230 to 250°F), is then mixed with the atomized absorbent in the reactor tower inlet disperser. In addition to providing a gas/absorbent mixing zone, the disperser imparts a rotational velocity to the flue gas. This intensifies the mixing with the absorbent and maximizes the effective residence time of the flue gas within the reactor. A hopper with a rotary valve permits the removal of the fly ash and reaction products that fall out in the tower. The reactor outlet gas is at 160 to 170°F. Both a three-field ESP and a fabric filter are part of this pilot program. Each field of the pilot ESP is equipped with its own individual high-voltage electrical supply and rapping mechanism for both discharge and collecting electrodes. The discharge

electrodes are round spiral wire electrodes with a diameter of 2.5 mm. There are four parallel gas passages through the ESP. The collecting electrodes provide an effective collecting area of 825 sq ft. The ESP gas flow can be varied, but a nominal flow of 2100 acfm will be used to compare performance to the full-scale units.

The parallel fabric filter is a high-ratio type with an air-to-cloth ratio of 5 to 6 ft/min. Both sodium and calcium sorbents are being tested. Sodium is in the form of a sodium carbonate solution produced as a by-product in the production of soda ash from trona. Several impurities, such as silica and chlorides, are present in this sodium liquor. Pebble lime is slaked in an open circuit wet ball mill to form a 15 weight percent solids slurry.

Nine on-site engineers perform the sampling and testing at Jim Bridger. Eight test blocks, consisting of short-term parametric tests and long-term reliability runs, will be completed.

Flue gas sampling consists of pitot tube traverses, particulate sampling, Orsat analysis, and SO_2 analysis. Continuous monitoring instruments are provided for flow, pressure, temperature, SO_2 (DuPont 460), and opacity (Lear-Seigler RM41). An on-site laboratory provides daily analyses of liquid and solid samples, including sulfite, total oxidizable sulfur, carbonate, sodium, and calcium. All major process variables are continuously monitored and recorded. These data are simultaneously stored in an on-site computer which also reduces the data for final analysis.

Information Sources

Shareef, Syed. Telephone conversation with James Farrington, Flakt. July 23, 1980.

Farrington, James. Personal communication with Syed Shareef. July 25, 1980.

3.12 JOY/NIRO

Address: Joy Industrial Equipment Company
Western Precipitation Division
4565 Colorado Boulevard
Los Angeles, California 90039

Niro Atomizer, Inc.
9165 Rumsey Road
Columbia, Maryland 21045

Contact for More Information: Jim Meyler
Joy/Western Precipitation Division
(213) 240-2300

Steven M. Kaplan
Niro Atomizer, Inc.
(301) 997-8700

Background

The Joy/Niro team was invited by Basin Electric to pilot a spray dryer-based dry FGD system at their Antelope Valley Station. In mid-November 1977, design work was begun on a pilot unit to be built at Otter Tail Power's Hoot Lake station. The pilot unit included a 20,000 acfm spray dryer followed by a 3000 acfm electrostatic precipitator and a 9000 acfm baghouse in parallel. The baghouse had four compartments and 60 one-foot diameter bags. The pilot unit was constructed from late November to mid-February and first operated from mid-February to April 24, 1978. During this period sodium carbonate and lime sorbents were tested, and design data were acquired for use in preparing a bid for the Basin Electric Antelope Valley Station FGD system. Parametric studies of the effects of inlet and outlet temperatures, stoichiometric ratio, recycle techniques, and particulate collector type on SO_2 removal were included in this test work. A 100-hr demonstration run of the pilot unit at Antelope Valley design conditions was also included.

Niro and Joy returned to Hoot Lake in mid-September 1978 to acquire data for preparing a bid on Basin Electric's Laramie River Station and to verify data from the previous test work. During this mid-September to mid-December 1978 test period, some 30 to 40 thousand data points on FGD performance were acquired. Also, during this period rail cars of Laramie River coal were shipped to Hoot Lake to operate the 60-MW Unit 2 boiler for several days at Laramie River conditions. The Laramie River ash was reported to be quite cementitious, but no operating problems were incurred during this period. Some tests were conducted adding water treatment sludge to the atomizer feed, and this was found to be a suitable method of disposal for the sludge. Some testing was conducted with commercially available ground limestone as a sorbent with very limited success. Other testing included SO_2 spiking up to a 4500 ppm flue gas concentration.

To date, Joy/Niro has been awarded contracts for five commercial utility systems at Antelope Valley, Sunflower Electric's Holcombe Station, Platte River Rawhide Station, and two units at Tucson Electric Power's Springerville Station. In addition, a contract has been awarded for a commercial industrial system to be installed on a carbon-regeneration furnace operated by Calgon, and for a 110 MW_e system at Northern States Power Company's Riverside Station which will be operated as a demonstration unit in the near future.

All current FGD research activities are being done on a new FGD pilot unit at the Niro Copenhagen research facilities.

Research and Development

Joy/Niro has no plans for any large scale demonstration activities other than the tests planned at the recently constructed Northern States Power System facility. Joy/Niro feels the technology has been and will be adequately demonstrated in past and current programs. Niro is, however, continuing to operate a small pilot facility in Copenhagen on a full schedule to prepare bids and conduct fundamental research. Joy/Niro feels that it is extremely important to evaluate the specific coal and ash characteristics for a particular site before bidding a system. Coal and ash characteristics have an important effect on achievable SO_2 removal efficiency, but it is difficult to quantify these effects. As an example, development of a predictive relationship between fly ash alkalinity and SO_2 removal or sorbent utilization has not been possible based on the data obtained to date.

The Copenhagen facility can treat about 5000 acfm of the flue gas. The unit is equipped with a pulse-jet fabric filter, a reverse air fabric filter and an ESP for particulate collection.

Commercial Systems Under Construction

Construction of both the Antelope Valley and the retrofit Northern States Power (NSP) systems is on schedule, despite a brief electrical workers' strike at NSP. At Basin Electric's Antelope Valley Station, the baghouse construction is nearly complete and three of the five spray dryer modules were almost fully assembled as of July 1980. Commercial operation of the Antelope Valley Station is currently scheduled for around April of 1982. Construction of the FGD system is proceeding on schedule. Current plans call for the entire SO_2 removal system (spray dryer and baghouse) to be "air-tight" by next summer.

The spray dryer, associated duct work, and reagent (lime) handling system at Northern States Power Company's Riverside Station were nearly complete in July 1980. Construction of the baghouse is on schedule but has not been completed. The existing ESP for Units 6 and 7 at the Riverside Station will be used for particulate collection in the initial tests. Testing of the spray dryer/ESP system is scheduled to begin this fall and run through December, after which the spray dryer will be operated in combination with the baghouse. The system will be a relatively large scale demonstration unit (two 65 MW_e boilers — up to 680,000 acfm combined). A slipstream (300,000 acfm) of flue gas will be used in the spray dryer/ESP tests. Several other system parameters and performance goals will be evaluated during the course of the three-year demonstration program. Immediate

plans for the spray dryer/ESP tests call for variation of the target SO_2 removal efficiency (70 and 90 percent), percent solids in the feed solution, and temperature drop over the spray dryer. Three types of fuel can be fired in the Riverside boilers: a 1 percent S coal, a 3 to 3.5 percent S coal, and a high sulfur coke for blending. Joy/Niro expects the system to achieve 90 percent SO_2 removal with the 3 to 3.5 percent S Coal. The inlet gas temperature will range from 300 to 350 F.

When the spray dryer/fabric filter tests begin, several different bag fabrics will be evaluated. These tests will provide important "full-scale" data on bag life and pressure drop characteristics of bag fabrics that may allow Joy to include less expensive fabrics in future commercial system bids.

Two different types of lime slaking systems will be available at Riverside: a ball mill slaker and an attrition slaker. Provisions also exist for recycle of the solids that drop out of the spray dryer and solids collected from the ESP or baghouse. No hot or warm gas bypass provisions are included in the Riverside system design.

Previous Joy/Niro work has indicated an extremely strong relationship between SO_2 removal and the approach to saturation at the dryer outlet. In testing at Riverside, the approach to saturation will vary between 15 and 35 F when the spray dryer/ESP system is tested, with an 18 to 20 F approach seen as the probable optimum operating condition. The spray dryer absorber appears to be fairly effective in removing SO_3. Any corrosion that was observed in previous tests was found to result primarily from a lack of insulation.

There were some difficulties associated with the retrofit requirements of the Riverside system design. The biggest problem was fitting the 46-ft diameter spray dryer in between the existing boiler building and coal handling facilities; it was a close fit and a hole had to be dug for the spray dryer to fit beneath the coal conveyor belt. No space limitation problems were encountered with the baghouse portion of the system, but it had to be elevated to allow passage of rail cars on existing tracks. The Riverside absorption module is the same size as a single module used in Joy/Niro's utility design. Also, the computer control system at Riverside is similar to the one that has been included in other system designs.

At the end of the demonstration test period (about 3 years), NSP will use the 10-compartment fabric filter to meet applicable particulate emission limits (various numbers of compartments will be on line when the spray dryer/fabric filter system is tested).

Commercial Systems Awarded Since Fall 1979

Joy/Niro has been awarded contracts for four utility systems since the Fall of 1979. Under the contracts for three of the utility systems (two 350-MW units at Tucson Electric Power's Springerville Station and the 250-MW Platte River Rawhide Station), Joy/Niro will only specify the design for the system and supply the equipment; a separate contractor will erect the system in the Tucson case, while Platte River has retained an option to have Joy/Niro erect that system. Responsibility for waste disposal has also been included in the contract for the fourth utility system to be supplied for Sunflower Electric's 310-MW unit at the Holcombe Station.

Basically, the system designs are very similar: a lime-based spray dryer followed by a reverse-air baghouse. Site specific factors such as coal sulfur content, flue-gas temperature, SO_2 removal requirements, and fly ash alkalinity may result in the incorporation of hot or warm gas bypass or solids recycle into the system design. Platte River and Sunflower will both fire a western subbituminous coal while Tucson will burn a New Mexico coal. Platte River and Sunflower are scheduled to start up in 1983. Tucson's two systems are scheduled to start up in 1984 and 1986.

The only industrial system Joy/Niro has sold to date will be installed on a carbon-regeneration furnace operated by Calgon. The 57,000 acfm of flue gas to be treated exits the furnace at 1700 F and contains up to 8000 ppm of SO_2/SO_3 and equivalent amounts of other halogen-based contaminants. The sorbent will be a sodium carbonate solution, and the dryer outlet temperature will be about 225 F.

Future Activities

Joy/Niro has recently submitted a bid for Sierra Pacific Power and Idaho Power's new Unit 2 to be constructed at the Valmy, Nevada Station. Sierra Pacific and Idaho Power specified a dry system for this new 250 MW unit; they also specified rotary atomization.

Information Sources

Kelly, M.E. and Syed Shareef. Meeting notes, Joy, Los Angeles, California. June 23, 1980.

3.13 KENNECOTT CORPORATION (CARBORUNDUM ENVIRONMENTAL SYSTEMS)

Address: Carborundum Environmental Systems
Kennecott Corporation
P.O. Box 87
9111 Cross Park Drive
Knoxville, Tennessee 37901

Contact for More Information: Hank Majdeski
Manager, SO_2 Project
(615) 693-7550

Background

Carborundum has conducted pilot-scale dry injection studies (1000 acfm) at their University of Tennessee facility and pilot unit tests on a 15,000 acfm spray dryer/baghouse system at Basin Electric's Leland Olds Station. Dry injection tests were run with both sodium bicarbonate and nahcolite. Temperatures of the entering flue gas ranged between 270 and 300°F, while entering SO_2 concentration ranged from 1000 to 4000 ppm. Results of the major portion of the test work are considered proprietary.

Research

Testing was scheduled to begin in July of 1980 at the University of Tennessee on a 1000 cfm spray dryer/baghouse pilot plant. This pilot plant serves basically as an extension on the original work done at the Leland Olds Station of Basin Electric. Some of the more important aspects of the testing to be conducted at the pilot plant will be performance of the system at high inlet SO_2 concentrations and the effect of recycle. Additionally, the use of nozzles for atomization will be investigated.

Gas for the pilot plant will be a slipstream off an existing spreader-stoker boiler with supplemental fly ash being added with a separate injection system for certain tests. The primary sorbent tested will be lime, although tests will also be conducted with sodium-based sorbents. Testing is expected to continue through the rest of the year. However, the facility will be maintained intact even after completion of initial testing for additional work that may be required in the future. Although the pilot plant gas flow rate is low, the baghouse portion of the system utilizes full size bags, resulting in a fairly low air-to-cloth ratio.

Commercial Status

Carborundum Environmental Systems has been awarded a contract by the University of Minnesota to supply two spray dryer/baghouse units, each to treat 120,000 acfm of flue gas from the campus physical plant's coal-fired boilers that will be used for co-generation. This commercial unit is expected to go into operation in the Fall of 1981. Two 83 MW_t boilers will fire subbituminous coal with sulfur content of 0.6 to 0.7 percent. Lime will be used as sorbent, and the design SO_2 removal efficiency is 70 percent.

Carborundum Environmental Systems has also entered into a technical license agreement with Kochiwa Kakohki of Japan. Kochiwa, having over 250 operating spray dryer installations throughout Japan and the Far East, will provide design technology and assistance for atomization spray dryer hardware.

Information Sources

Shareef, Syed A. Telephone conversation with Hank Majdeski, Kennecott Development Co. June 5, 1980.

3.14 KOCH ENGINEERING

Address: Koch Engineering Co., Inc.
161 East 42nd Street
New York, New York 10017

Contact for More Information: Mike Mugsakis
(212) 682-5755

Background

Koch began development of a spray dryer-based dry FGD system in early 1979. The company was reported to be ready to accept orders for commercial systems in July 1980. Results of all tests performed by Koch are considered proprietary.

Research and Development

Koch Engineering has recently purchased a coal-fired boiler which was to be installed by the end of July 1980. The boiler will be used for test work on customers' coal in order to provide guarantees of performance for the spray dryer system. Tests on both rotary and nozzle atomizers have been performed, and nozzles seem to be the likely choice for Koch's commercial systems.

Commercial Activities

An agreement has been signed between Koch and Mikropul to work jointly at Mikropul's dry scrubbing system at Strathmore Paper Company.

Information Sources

Shareef, Syed. Telephone conversation with Mike Mugsakis, Koch Engineering. June 6, 1980.

3.15 MIKROPUL

Address: Mikropul Corporation
10 Chatham Road
Summit, New Jersey 07901

Contact for More Information: Tom Reinauer
Vice President of Engineering
(201) 273-6360

Background

Mikropul is a division of U.S. Filter, which includes Ducon, a wet scrubber manufacturer. Mikropul began work on a spray dryer-based FGD system in January 1978. Bayliss Industries supplied the spray dryer technology. As the result of their work, Mikropul was awarded a contract in late 1978 to provide a spray dryer/baghouse system for an industrial coal-fired boiler at Strathmore Paper Company at Woronoco, Massachusetts.

Commercial Activities

Mikropul's lime-based spray dryer/baghouse system at Strathmore Paper Company has now been in operation for eleven months. Initially, Mikropul had started with technical assistance from Bayliss Engineering on spray dryer design but is now collaborating with Koch Engineering. Strathmore's 85,000 lb steam/hr pulverized coal boiler burns about 75 tons coal/day. The sulfur content of the coal ranges from 2.3 to 3.0 percent. Based on the results obtained with a DuPont 460 analyzer, the SO_2 removal efficiency is 70 to 80 percent at a lime stoichiometric ratio of 1.2. The dry scrubbing system has now been operational for over 7000 hours during the past eleven months. After discounting maintenance and holiday shutdowns, this corresponds to greater than 90 percent operability based on boiler demand.

Mikropul is continuing in-field developmental work toward improved performance of the system. Most of the early operational problems have now been solved. For instance, the acrylic bags initially used by Mikropul shrank within the first month of operation. After considerable developmental effort, Mikropul employed an improved finishing

technique, which is considered proprietary, to develop bags that were not susceptible to shrinkage. The new bags were installed in October 1979. These bags have since been analyzed every month and the strength has been shown to hold very well. Also, the bag material is washable and, therefore, easy to clean. No moisture condensation has been observed on the bags or the clean gas plenum. The bag retainers are epoxy coated, while the hoppers and tube sheets are stainless steel. No corrosion problems have been encountered so far.

Some problems were caused by excessive plugging of nozzles when steam atomization was used, requiring frequent cleaning. However, they have been able to sustain operation at design removal with 2 out of 4 nozzles operating. Usually, it takes about 3 minutes to inspect and remove a non-operating nozzle and install a replacememt. Temperature probes develop temperature profiles which can indicate when a nozzle might not be operating satisfactorily. Koch Engineering is currently working on the development of a modified nozzle for Mikropul. The new nozzles to be evaluated at Strathmore, will be designed to reduce energy consumption and for continuous operation with both air and steam.

Another problem that Mikropul faced during the early phase of operation was the wetting of the spray dryer walls, leading to accumulation of wet solids. This problem was eliminated by some aerodynamic design changes in the dryer by Koch Engineering. Even if the spray dryer's walls are dry, there can be some accumulation. However, the walls are easily cleaned by mechanical rapping.

The use of chemical additives manufactured by Mikropul's sister company, Drew Chemicals, has resulted in improved lime slurry handling characteristics.

Future Activities

Currently, all of Mikropul's developmental activities are being conducted in-field at Strathmore. They have submitted several bids for commercial installations. No decisions have been made on these bids yet. Although Mikropul has concentrated mainly on two-fluid nozzles for atomization, they also offer centrifugal atomizers for commercial system designs.

Information Source

Shareef, Syed. Telephone conversation with Tom Reinauer, Mikropul. August 14, 1980.

3.16 RESEARCH-COTTRELL AND EPA/RESEARCH COTTRELL (COTTRELL ENVIRONMENTAL SCIENCES)

Address: Research-Cottrell, Inc.
Cottrell Environmental Sciences, Inc.
P.O. Box 1500
Somerville, New Jersey 08876

Contact for More Information:

Research: N.J. Stevens
Manager
Chemical Process Development
(201) 685-4887

Commercial: H.H. Braden
Manager
Power Industry Sales and Marketing
(201) 685-4284

Research and Development

Research-Cottrell, Inc. (Cottrell Environmental Sciences) has received a contract from the Environmental Protection Agency (EPA) for a pilot plant study of a spray dryer/fabric filter system. The pilot study is being conducted at the Comanche Station of Public Service of Colorado in Pueblo, Co. The study is expected to help EPA define the technical limits of applicability of dry scrubbing for low and medium sulfur Western coals. Completion of the program is scheduled for February 1981.

The test program is investigating the effect of the key process variables on SO_2 removal in the spray dryer and fabric filter. For the spray dryer, the following process variables are under study:

- External Process Variables
  - Lime/SO_2 stoichiometry
  - Flue gas SO_2 concentration
  - Flue gas temperature
- Recycling Scrubber Wastes/Reagent
  - Weight percent recycled
  - Source of waste (spray dryer or baghouse)
- Spray Dryer Equipment Variables
  - Disc speed
  - Disc diameter
  - Atomizer design
  - Slurry physical properties
  - Slurry feed rate
  - Gas residence time
- Reagent Studies
  - Lime slaking
  - Particle size reduction
  - Fly ash reactivity

Fabric filter variables include air-to-cloth ratio and pressure drop.

The final phase of the field test program will be a continuous demonstration of the spray dryer/fabric filter. The primary purpose of the demonstration run is to verify that the system can achieve the required SO_2 removal on a sustained basis. Selection of the demonstration run operating conditions will be made based on the process variable test results.

The characteristics of the solid wastes produced from the dry scrubbing system will be evaluated. Materials generated at the pilot test site will be examined in laboratory test facilities. The testing will be aimed at determining 1) the chemical composition of the waste products and 2) the soil mechanical and leaching properties of the FGD solids/flyash mixtures. The latter tests include characterization of the wastes with respect to:

- compacted density,
- triaxial compression,
- permeability, and
- leachate composition.

Commercial Activities

In December 1979 Research-Cottrell was awarded a contract to provide a spray dryer-based dry FGD system for the Stanton Station of United Power Association, Stanton, North Dakota. The unit is scheduled to go into service in 1981. The 65-MW_e boiler will be fired with low and intermediate sulfur sub-bituminous Montana coal.

Research-Cottrell has completed preliminary pilot work at two locations where data have been collected on Texas lignite and Powder River Basin fuel. The company is now in a position to scale-up designs to those required for large utility boilers. Research-Cottrell anticipates using multiple atomizers per dryer vessel. Design of the reagent feed system slaker, gas handling, temperature control, and other components have been developed for initial dry system application based on Research-Cottrell's wet FGD system experience. The fabric filter inlet gas temperature will be maintained at 40 to 50°F above the adiabatic saturation to promote flue gas buoyancy and to protect the collector bags from acid and moisture condensation.

Research-Cottrell's experience has shown that nozzle atomizers are the logical choice for sodium-based sorbents. Rotary atomizers, however, have been found to be superior in calcium systems because they are less susceptible to pluggage and erosion.

Information Sources

Shareef, Syed A. Telephone conversation with Kishor Parikh, Research-Cottrell. June 4, 1980.

Shareef, Syed A. Telephone conversation with Nicholas J. Stevens, Research-Cottrell. June 20, 1980.

Stevens, Nicholas J. Personal communication with Syed Shareef. June 25, 1980.

3.17 ROCKWELL INTERNATIONAL

Address: Environmental & Energy Systems Division
Rockwell International
Energy Systems Group
8000 DeSoto Avenue
Canoga Park, California 91304

Contact for More Information: Dr. Dennis G. Gehri, Project Manager
ACP Research, Development and Applications
Rockwell International
(213) 341-1000

Background

The Rockwell/Wheelabrator-Frye venture sold two commercial systems: a 410-MW utility boiler system to Otter Tail Power Company (Coyote Station) and an industrial system (65,000 acfm) to Celanese Fibers Company. Both are spray dryer/baghouse systems. Soda ash is the sorbent for Coyote, while lime (no recycle) is used at Celanese.

Rockwell and Wheelabrator-Frye dissolved their joint venture in January 1980. Both companies will continue to be involved in existing projects for the near future. For future commercial sales, Rockwell will bid the entire system and subcontract the particulate collection portion of the process.

Wheelabrator-Frye will remain in the dry scrubbing market, drawing on experience of some of their other divisions and subsidiaries to design, fabricate, and install a complete spray dryer/baghouse system.

Research and Development

Rockwell's primary R&D site has been a 5000 acfm pilot spray dryer installed at Commonwealth Edison's Joliet Station. The system includes reverse-air and pulse-jet fabric filters and an ESP for particulate collection. Initial start-up and checkout testing began in July 1979. In October the various optimization and parametric tests were started. The system is

currently operating 5 days/week, 1 shift/day. Tests are expected to continue through August 1980. Results for public release are not available at this time, but may be presented at upcoming symposia.

The Joliet unit has been used primarily for preparing bids and conducting pilot-scale research into some of the finer points of the technology. The early focus was on testing with lime. Five weeks of testing with sodium-based alkalis was started in June. (The results of the sodium tests will also serve to verify Coyote removal guarantees.) The inlet SO_2 concentration is 300 to 400 ppm with provisions for spiking up to 1000 ppm. The Joliet unit also has provisions for warm or hot gas bypass and solids recycle.

Both a paste slaker and a ball mill slaker are available at Joliet. The relative merits of the two slaking methods can be summarized as follows:

- Paste slakers, in addition to having lower first costs and power requirements, produce a less abrasive slurry reducing wear and maintenance requirements for pumps and pipes.

- Ball mill slakers have an advantage over paste slakers in that there is no grit removal stream to dispose of. Also, ball mills generally produce a more finely ground sorbent and lead to a more reactive slurry. And although ball mills produce a somewhat more abrasive slurry, no major pump problems have occurred at pilot units with ball mill slakers.

The mobile unit used by Rockwell in testing at various locations last year (including PP&L's Jim Bridger plant) has been reassembled at their Canoga Park facility. The 10,000 cfm unit is currently being used to gather data for bid preparation and to conduct fundamental research. No firm test locations could be made public, but it is likely that the mobile unit will be moved to one or more test sites within the year.

In addition to the R & D activities at Joliet and with the mobile unit, Rockwell has a 200 cfm spray dryer for bench-scale studies. (This spray dryer is also part of a small-scale mock-up of Rockwell's regenerable ACP.)

One of the areas Rockwell has been investigating is the dry scrubbing reaction mechanism. For sodium-based spray drying, the reaction appears to be limited by transfer of gaseous SO_2 to the liquid phase. For a lime-based spray dryer, the reaction is limited more by the mobility of the alkaline species in the slurry droplet. However, Rockwell feels that residual moisture in the spray-dried solids is not as much of a determining factor as proposed by other vendors. This is especially true in the SO_2 removal reaction occurring across the fabric filter cake, which Rockwell theorizes to be essentially a gas/solid reaction.

Rockwell believes that the sorbent preparation, spray drying, and particulate collection portions of the dry scrubbing process are fairly well understood. The biggest uncertainties have to do with waste disposal. Rockwell has been investigating several methods of solids disposal including pelletizing, briquetting, and determining possible uses for the wastes.

Commercial Activities

Rockwell's industrial system at Celanese Fiber Company's Ancelle plant has passed Maryland State compliance tests. The system is now being operated by Celanese after initial performance testing was conducted by Rockwell/W-F. There have been a few operating problems recently, although none of them have to do with the dry system's capability to meet design removal conditions. One of the biggest problems has been the availability of coal with a sulfur content equal to or less than the maximum design coal sulfur content of 2 percent. The sorbent slurry pumps are somewhat undersized for the system to achieve high SO_2 removal efficiencies when a 3 to 3.5 percent sulfur coal is burned.

Rockwell presently has three utility bids being evaluated. One should be announced sometime in late 1980, but evaluation of the other two has been delayed. The Rockwell/Wheelabrator-Frye former joint venture has recently been issued a patent on their two-stage dry system.

Future Activities and Plans

Major emphasis will continue to be placed on investigating the finer points of spray drying technology to allow for refinement and wider application of the process. Rockwell feels that the limiting factor in high sulfur coal applications is the reagent cost differential between lime and limestone used in conventional wet systems.

As for industrial systems, Rockwell plans to have a standard system design for "quick-bid" preparation. Site specific factors may then require addition of recycle or bypass provisions.

Information Source

Kelly, M.E. and Syed Shareef. Meeting notes at Rockwell International, Los Angeles, California. June 24, 1980.

3.18 STORK-BOWEN ENGINEERING, INC.

Address: Stork-Bowen Engineering, Inc.
P.O. Box 898
Somerville, New Jersey 08876

Contact for More Information: Edward Biedell
Senior Process Engineer
Air Pollution Control Systems
(201) 725-3232

Background

A gas cleaning process originated by Leisegang Umwelttechnik KG, Berlin, reportedly incorporates the higher removal efficiency advantage of a wet scrubber with dry waste product capability of a spray dryer. Patents on the scrubber design have been issued by the U.S., South Africa, Spain, and are expected from several other countries. Stork-Bowen Engineering, Inc. is the exclusive licensee for this process in the U.S., Canada, and Mexico.

Research

The Stork-Bowen/Leisegang (SB/L) process is particularly geared toward small- and medium-scale industrial gas cleaning applications. High removal efficiencies are reported using conventional reagents, such as lime, for SO_2 removal. Solids formed by reaction plus particulates in the entering gas stream are collected in the scrubber slurry and then returned to the spray dryer to be discharged as a neutral dry power. In addition to particulates, the SB/L process can control contaminants such as SO_2, SO_3, HCl, HF and other acid gases from chemical plants, smelters and other minerals operations, foundries, and waste incinerators.

For high SO_2 concentrations, coupling the spray dryer and a wet scrubber makes possible the handling of concentrations of at least up to 5000 ppm of SO_2 and high concentrations of SO_3, HCl and HF. Removal efficiencies of over 95% are reported to be achievable.

A flow sheet of the SB/L process is shown in Figure 3-4. The process operates as follows. Hot flue gas first passes through a quenching tower to reduce the temperature and then passes through a spray dryer/reactor, where it is contacted with a fine atomized spray of slurry. The gas is cooled and partly saturated, and absorption of about 20 to 30 percent of the gas contaminants occurs. Inlet gas temperatures to the spray dryer/reactor needs to be only high enough to evaporate the water from the reactant.

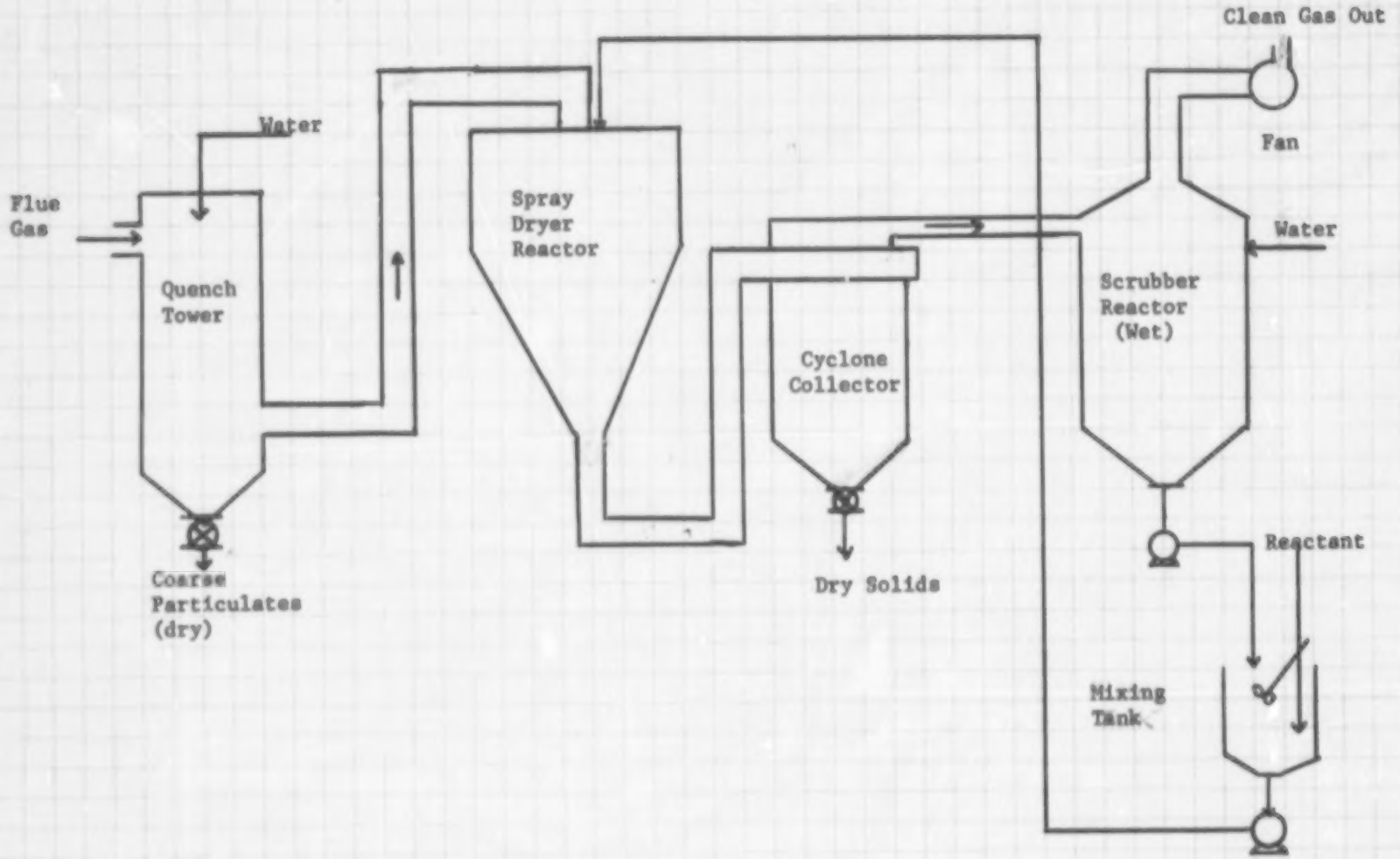

Figure 3-4. Stork-Bowen/Leisegang Process For Gas Cleaning

The dry powder formed in the spray dryer is conveyed to the high efficiency cyclone collector which separates the airborne solids. The solids consist of reaction products from both the spray dryer and wet scrubber plus particulates.

After the cyclone, the gas flows into a venturi scrubber in which the finest dust is separated and final absorption of the sulfur dioxide, fluorine, and/or hydrogen chloride is carried out. The suspension generated in the scrubber is pumped into a mixing tank which serves as a receptor for the addition of an alkaline reagent. The slurry from the mix tank is fed into the spray dryer where the water is evaporated (the water makeup is added in the venturi scrubber). The saturated flue gas leaves the scrubber via an induced draft fan.

The SB/L process is not limited to using the Leisegang scrubber and other scrubber manufacturers have been contacted for the use of their equipment. For example, if particulate removal was not required as part of a gas clean-up system, a different type of scrubber would be substituted for the Leisegang venturi scrubber. Thus, for treating SO_2 emissions only, a low pressure drop scrubber, such as a spray tower, could be used.

Commercial Status

The first major installation of the SB/L process went on-stream in mid-1979 on a cupola furnace exhaust at a large foundry in West Germany. This system uses a lime sorbent and is reported to reduce SO_2, HF, and particulate emissions to well below the applicable code. Table 3-12 lists the system design parameters.

As is typical of foundries, the gas end particulate removal requirements vary widely during process operation. Also, shutdown/startup cycles are more frequent than the typical power plant or large chemical plant operation. However, emissions from the plant are typically below 0.003 grains/scf for SO_2 and below 0.002 grains/scf for HF. Particulate discharge in the tall gas stack is about 0.125 kg/ton of molten iron, which is half the code requirement.

Information Sources

Shareef, Syed. Telephone conversation with Edward Biedell, Stork Bowen. June 4, 1980.

Biedell, Edward L. Personal communication with Syed Shareef. June 9, 1980.

Biedell, E.L. and D.W. Belcher. "New Gas Cleaning System Combines Wet Dry Process." Iron and Steel Engineer. June 1980.

TABLE 3-12. STORK-BOWEN/LEISEGANG INSTALLATION AT KLÖCKNER-WERKE AG, MANNESTAEDT PLANT, FEDERAL REPUBLIC OF GERMANY

Application:	Hot blast Cupola Furnace (14 tons/hour)
Pollutants:	Particulate (Iron) SO_2 HF
Emissions Limits:	
Particulate	0.25 kg/ton molten iron
HF	<5 mg/Nm^3 dry gas (0.002 gr/scf)
SO_2	≥90% removal
System Guarantees:	
Particulate	0.125 kg/ton molten iron
HF	5 mg/Nm^3 dry gas (0.002 gr/scf)
SO_2	≥95% removal (0.003 gr/scf)
Chemical Reagent:	Hydrated lime - $Ca(OH)_2$
Gas Capacity:	30,000 acfm
Contract Awarded:	January 1979
System Start-Up:	August 1979 [a]

[a]Achieved all systems guarantees and successfully passed performance tests for compliance with government regulations.

SECTION 4

RECENT DRY FGD LITERATURE

1. Banks, R.B. and M.L. Hochhauser. "Desulfurization of Flue Gas with Nahcolite in a Pilot Fabric Filter." (Presented at the 71st Annual Meeting of the Air Pollution Control Association. Houston, Texas. June 25-30, 1978.)

2. Blythe, G.M., J.C. Dickerman and M.E. Kelly. "Survey of Dry SO_2 Control Systems." EPA-600/7-80-030. Radian Corporation. Durham, North Carolina. February 1980. (NTIS PB 80166853)

3. Burnett, T.A. and W.E. O'Brien. "Preliminary Economic Analysis of a Lime Spray Dryer FGD System." EPA-600/7-80-050. TVA Office of Power. Muscle Shoals, Alabama. March 1980. (NTIS PB 80190051)

4. Buschmann, J.C. et al. "Disposal of Wastes from Dry SO_2 Removal Processes." (Presented at 1980 Joint Power Conference. Phoenix, Arizona. September 1980.)

5. Davis, W.T. et al. "Research on the Simultaneous Removal of SO_x and Particulates from Stoker-Fired Boilers." (Presented at the 70th Annual Meeting of the Air Pollution Control Association. Toronto, Canada. June 20-24, 1977.

6. Davis, W.T., T.C. Keener and L.L. Lavely. "Research on the Removal of SO_2 by Additive Injection Techniques on a Stoker-Fired Boiler." (Presented at the 71st Annual Meeting of the Air Pollution Control Association. Houston, Texas. June 25-30, 1978.)

7. Downs, W., W.J. Sanders and C.E. Miller. "Control of SO_2 Emissions by Dry Scrubbing." (Presented at the American Power Conference. Chicago, Illinois. April 21-23, 1980.)

8. EPRI. "SO_2 Control by Dry Sorbent Injection." EPRI Journal. June 1980. p. 52.

9. Furlong, Dale A., T.G. Brna, and R.L. Ostop. "SO_2 Removal Using Dry Sodium Compounds." (Presented at the 89th National AIChE Meeting, Portland, Oregon. August 17-21, 1980.)

10. Genco, J.M. et al. "The Use of Nahcolite Ore and Bag Filters for Sulfur Dioxide Emission Control." In: Journal of the Air Pollution Control Association. 25:12 December 1975. pp. 1244-1253.

11. Getler, J.L. et al. "Modeling the Spray Absorption Process for SO_2 Removal." In: Journal of the Air Pollution Control Association 29:12. December 1979. p. 1270.

12. Glasmer, Robert D. et al. "Limestone/Coal Fuel Pellet - A Viable Method to Control SO_2 Emissions from Industrial Boilers." (Presented at the 73rd Annual Meeting of the Air Pollution Control Association. Montreal, Canada. June 22-27, 1980.)

13. Hurst, T.B. "Dry Scrubbing Eliminates Wet Sludge." (Presented to Joint Power Conference. Charlotte, North Carolina. October 7-11, 1979.)

14. Kaplan, Steven M. and Karsten Felsvang. "Spray Dryer Absorption of SO_2 from Industrial Boiler Flue Gas." (Presented at the American Institute of Chemical Engineers 86th National Meeting 10th Petro Expo. Houston, Texas. April 1-5, 1979.)

15. Martin, J.R., W.B. Ferguson, and D. Frabotta. "C-E Dry Scrubber Systems: Application to Western Coals." (Presented at the American Power Conference. Chicago, Illinois. April 21-23, 1980.)

16. Meyler, J.A. "Dry Flue Gas Scrubbing: A Technique for the 1980's." (Presented at 1980 Joint Power Conference. Phoenix, Arizona. September 1980.)

17. Onnen, James, "Wet Versus Dry Sulfur Dioxide Removal Study." (Presented at the Third Annual Fabric Filter Alternatives Forum. Phoenix, Arizona. Conference co-sponsored by Arizona State University and American Air Filter. September 20-21, 1978.)

18. Stern, J.L. "Dry Scrubbing for Industrial Flue Gas Desulfurization: State-of-the-Art, 1980." (Presented at the 89th National Meeting of AIChE. Portland, Oregon. August 17-20, 1980.)

APPENDIX

CONVERSION FACTORS

1 ft	=	0.3048 m
1 short ton	=	0.91 metric ton
1 lb	=	0.454 kg
1 gal	=	3.79 liters
1000 cfm	=	0.5 m^3/s
1 gal/1000 ft^3	=	0.13 liters/m^3
1 Btu	=	1.055 kJ